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RADTRAN 5

User Guide

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ABSTRACT

This User Guide for the RADTRAN 5 computer code for transportation risk analysis describes basic risk concepts and provides the user with step-by-step directions for creating input files by means of either the RADDOG input file generator software or a text editor. It also contains information on how to interpret RADTRAN 5 output, how to obtain and use several types of important input data, and how to select appropriate analysis methods. Appendices include a glossary of terms, a listing of error messages, data-plotting information, images of RADDOG screens, and a table of all data in the internal radionuclide library.

Acknowledgments

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1 Introduction and Overview

The RADTRAN computer code is used for risk and consequence analysis of radioactive material transportation. A variety of radioactive materials (RAM) is transported annually within this country and internationally. The shipments are carried out by overland modes (mainly truck and rail), marine vessels, and aircraft. Transportation workers and persons residing near or sharing transportation links with these shipments may be exposed to radiation from RAM packages during routine transport operations; exposures may also occur as a result of accidents. Risks and consequences associated with such exposures are the focus of the RADTRAN 5 code.

This User Guide is intended both for newcomers and for users of RADTRAN 4 (Neuhauser and Kanipe, 1992). The User Guide specifies and describes the required data, control inputs, input sequences, user options, and other information and activities necessary for execution of RADTRAN 5 Release 0. Throughout this guide important points and tips for users, both new and old, are highlighted by an arrow (➡).

1.1 History of RADTRAN

Sandia National Laboratories (SNL) in Albuquerque, New Mexico, developed the RADTRAN code. It was first released in 1977 (Taylor and Daniel, 1977) in conjunction with the preparation of NUREG-0170 (NRC, 1977). The analytical capabilities of the code have been expanded and refined in subsequent releases. RADTRAN II was released in 1983 (Madsen et al., 1983); and RADTRAN III was released in 1986 (Madsen et al., 1986).

RADTRAN 4 (Neuhauser and Kanipe, 1992) represented a major new direction for RADTRAN development. The user now could carry out route-specific analyses by assigning route-segment-specific values for a number of parameters (population density, vehicle speed, traffic count, etc.) to up to 60 route segments per run. These route-specific capabilities have been improved and expanded in RADTRAN 5, and a number of features have been added.

1.2 Features of RADTRAN 5

RADTRAN 5 may be used to evaluate radiological and nonradiological consequences of routine, accident-free transportation of radioactive materials, as well as radiological and nonradiological consequences and risks from accidents that might occur during transportation of such materials. RADTRAN 5 produces estimates of incident-free population dose, accident dose-risk, nonradiological mortality, and a suite of individual dose estimates. Doses and dose-risks[1] may be converted to health risks. Calculation of incident-free population dose considers persons adjacent to the route (off-link); persons in vehicles sharing the route (on-link), crew members, and persons at stops. Potential dose-risks are calculated for populations (1) downwind from hypothetical releases associated with accidents of varying severities or (2) within stated radial distances of loss-of-shielding accidents of varying severities.

The advances in RADTRAN do not prohibit former users of RADTRAN 4 from continuing to use old methods (e.g., unit-risk factors) or aggregate data (see Chapter 5). Improvements in the modeling of multiple-nuclide materials were introduced in RADTRAN 4, the first release of the code to permit direct analysis of multiple-package shipments made up of dissimilar packages. Those features have been retained in RADTRAN 5. RADTRAN 5 also carries forward several enhancements included in later maintenance releases of RADTRAN 4. For example, RADTRAN 5 now calculates the total exposed population by a method that accounts for population residence time (Smith, Neuhauser, and Kanipe, 1996), which is useful for analysis of multi-year shipping campaigns.

[1] Dose-risk is the product of a given consequence dose and its probability of occurrence.

1.3 Route-Specific Analysis

RADTRAN 5 permits highly route-specific analyses to be performed. As in RADTRAN 4, a route may be subdivided into segments with independent, user-assigned values for population density and other route-specific parameters. New features not found in RADTRAN 4 include (1) an expansion of the number of parameters that can be made segment-specific, (2) the capability to treat individual stops separately, and (3) the capability to treat each handling separately.

1.4 Radionuclide Library File

The internal library of radionuclide-related parameter values now contains an expanded array of data on 60 of the most commonly transported radionuclides. The user can also independently define additional radionuclides.

1.5 User-Definable Parameters Expanded

The trend away from fixed-value internal parameters that began with RADTRAN 4 has been continued in RADTRAN 5. Nearly all RADTRAN 5 parameters are now user-definable, and users familiar with earlier releases of RADTRAN will notice several new variable names. An array of "standard" or recommended values for many parameters is available. The user may employ all, some, or none of these values, as the needs of the analysis dictate. Parameters are defined and discussed in detail in Chapter 3. Analysis strategies are addressed in Chapter 4.

1.6 Maximum Individual Accident Dose

RADTRAN 5 now permits direct estimation of individual accident doses by a method that parallels the population-dose consequence calculation. The calculations differ in two essential features. (1) The minimum centerline downwind distance associated with a given time-integrated concentration may be included in the appropriate input-data array. The user may calculate distance values with dispersion codes such as INPUFF (Petersen et al., 1984). (2) The calculated population dose in an isopleth is divided by the total population in that isopleth. This simple arithmetic operation yields a mean individual dose to persons within a given isopleth, which may then be associated with the minimum centerline distance value for that isopleth. This capability was tested as an independent code, called TICLD (Transportation Individual Centerline Dose), prior to being incorporated into RADTRAN 5 (Weiner, Neuhauser, and Kanipe, 1993).

1.7 Ingestion Dose Model

A development goal has been to keep RADTRAN calculational methodologies reasonably parallel to the MACCS code (Melcor Accident Consequence Calculational System), now in its second major release, MACCS2 (Chanin and Young, 1997). The ingestion model formerly used in both MACCS and RADTRAN 4 is no longer the primary model used in MACCS2. A new model, COMIDA2, which is based on a dynamic food chain model, is now preferred (Abbot and Rood, 1994a,b). Values of ingestion-dose per activity unit of ground deposition have been pre-calculated for most radionuclides in the internal library.[2] The COMIDA2 module of MACCS2 may be used directly to obtain values for unusual isotopes or unusual situations. The dose values for prompt health effects also have been updated to be consistent with MaCCS2.

1.8 Nonradiological Fatalities

The expected numbers of fatalities from mechanical effects of traffic accidents are now calculated in RADTRAN 5 under keyword NONRAD. In the past, a separate code had to be used to obtain these values.[3]

1.9 Sensitivity and Uncertainty Analysis

[2] Ingestion factors are not calculated for radionuclides with half-lives of less than 1 hour.

[3] Only fatalities from accidents are calculated; hypothetical fatalities from inhalation of vehicle exhaust particulates are no longer calculated because toxicity thresholds for exhaust constituents are now well known and the unit-risk-factor approach can no longer be justified (see Chapter 5).

In previous releases of RADTRAN, the sensitivity of the incident-free dose result to variation of the input parameters could be analyzed. The analysis method depends on obtaining partial derivatives of linear equations in RADTRAN. With the advent of the capability to explicitly consider the neutron component of dose rate (if any) in RADTRAN 4, the calculation of incident-free dose could involve nonlinear relationships for which the partial-derivative method might prove inadequate. The partial-derivative method is still available, but other methods also may be employed. Sensitivity and uncertainty measures for RADTRAN analyses now may be obtained with the assistance of a separate computer code, the Latin Hypercube Sampling (LHS) code (Iman & Shortencarier, 1984). The LHS code can be used as a "shell" with RADTRAN (Mills et al., 1995) and is available on TRANSNET, the RADTRAN Internet site (see Chapter 3, Section 3.2.1). Classical Monte Carlo methods have been applied in the past (e.g., Neuhauser & Reardon, 1986) and still may be used.

1.10 Mathematical Models in RADTRAN 5

➡**RADTRAN 5 embodies several mathematical models of transportation environments that have been formulated to yield conservative estimates of integrated population dose and other metrics *in a way that can be supported by readily available data*.** Data gathering is usually the most expensive and time-consuming part of performing a risk analysis. Mathematical models more detailed than those in RADTRAN 5 can be and have been constructed, but most require at least some input data that either do not exist or would be expensive or impossible to obtain. An example of unobtainable data is detailed meteorological information for each point or segment of a route. The limitations imposed by data availability were explicitly acknowledged in the development of RADTRAN 5.

Details of the transportation environment that either have no effect on calculated risk values or reduce conservatism have been neglected in some RADTRAN 5 models. For example, all route segments are modeled as straight lines without grade or curves. This route-segment model provides ease of calculation and yields slightly conservative dose estimates (because the dose calculation involves integration to infinite distance from the package although actual route segments have finite lengths). In another example, all highway and rail links are treated as being one lane (or track) wide for the purpose of estimating distances to population beside the road or railroad. However, they are treated as being two lanes wide (one lane or track in each direction) for the purpose of estimating doses to persons in vehicles sharing the road or railroad. The first treatment achieves symmetry (and, hence, mathematical simplicity) around the lane in which the shipment is traveling. The second treatment (one lane each direction) yields the smallest perpendicular distance and, hence, the highest incident-free dose, to persons in vehicles traveling in the opposite direction. Thus, for this latter purpose, all rail routes are modeled as having double tracks, when in fact double tracks are not common. Such departures from absolute parallelism with physical reality have been used (1) when they simplify a calculation without either underestimating or greatly overestimating dose or risk, and (2) when they reduce expensive data-gathering requirements. For example, determining which railroad segments on any given route are single-track and which are double-track would add time and expense to an analysis but yield little or no improvement in the risk estimates at the recommended two-significant-digit level. Details of the mathematical models in RADTRAN 5 may be found in the RADTRAN 5 Technical Manual (Neuhauser, Kanipe and Weiner, 1999).

1.11 Technical Information Summary

RADTRAN 5 is written in ANSI Standard FORTRAN 77 (ANSI, 1978) and is operational on a HP-UNIX computer at SNL in Albuquerque, New Mexico. Execution time for a single problem is usually a few seconds. The input file is named R5IN.DAT. There are a total of 73 subroutines and functions in RADTRAN 5. The main routine is named RADTRN. Instructions for creating input files and for saving and renaming output files are given in Chapter 3. The results of intermediate accident-risk calculations are written to R5INTERM.DAT. Probability-consequence pairs are written to R5PLOT0.DAT, R5PLOT1.DAT, and R5PLOT2.DAT for later graphical or quality-assurance applications (see Appendix B).

1.12 Outline of User Guide

Chapter 2 defines essential terms and concepts that are used throughout this guide. Chapter 3 provides instructions for data entry and Chapter 4 is a guide to the output. Chapter 5 discusses options and strategies for performing analyses with RADTRAN 5 and describes the basic output. Appendix A is a Glossary of Terms. Appendix B describes the data from intermediate calculations written to output file R5INTERM.DAT and contains instructions on how to generate probability-consequence plots of the data with output files R5PLOT0.DAT, R5PLOT1.DAT and R5PLOT2.DAT. Appendix C contains a list of RADTRAN 5 error messages and suggested error-correction strategies. Appendix D contains images of screens produced by the RADTRAN 5 Input-File Generator (RADDOG). Appendix E contains the Radionuclide Data Library.

2 Transportation Risk - Concepts and Overview

A number of terms used throughout this User Guide have specific meanings in the fields of radiological risk analysis and RAM transportation. The most important of these, along with terms for underlying concepts of radioactivity and risk, are defined and explained in this chapter. A full Glossary of Terms may be found in Appendix A.

2.1 Risk and Risk Assessment

Risk is commonly defined as the product of a consequence and its probability of occurrence. What this means in the context of RADTRAN 5 is that transportation risks, like the risks associated with any complex process, may be decomposed into "what can happen…how likely things are to happen, and the consequences for each set [of things that can happen]" (Helton, 1991). As the terminology in this definition implies, set theory provides an ideal framework for formal expressions of risk.

For accident risk assessment, the answer to the first question ("What can happen?") is that the set of all accidents can be expressed as disjoint sets of accidents (S_i , i=1,...nS). In other words, sets of accidents such that

(1) no two sets contain any accidents in common (i.e., are disjoint),
(2) each set consists of accidents with similar outcomes, and
(3) the sets are jointly exhaustive (that is, all the sets taken together include the entire range of accidents from low consequence to high consequence).

"How likely things are to happen" can be defined as the probability that an accident in set S_i will take place. The "consequences for each set" consist of one or more specified consequence results (population dose, early morbidity, etc.) (Helton, 1991).

In accident risk analysis with RADTRAN 5, the set of all accidents for the mode(s) being analyzed must be divided by the user into subsets (i.e., into the subsets S_i, i=1,…,nS) as described above. The subsets also must satisfy the other conditions described in the previous paragraph. ➡***The term "similar outcomes" refers to similar package damage and not to any other features such as driver mortality or time of day.*** The subsets and their probabilities are most commonly developed by means of event-tree analysis, but are not required to be. In RADTRAN, these subsets are referred to as ***accident-severity categories***.

Corresponding probabilities are obtained from the products of accident rate and ***severity fraction*** values. ➡***Severity fraction* is defined as the conditional probability, given that an accident occurs, that it will be of a specified severity (i.e., belong to a given accident subset).** There are several legitimate ways of defining sets of occurrences for an analysis. However, the use of anecdotal accounts or other non-quantitative information is <u>not</u> among them. Examples of accident-severity category development include the work of Wilmot (1981), Fischer et al. (1987), and Sprung et al. (1998).

RADTRAN calculates distinct probability-consequence products for up to six exposure pathways for each accident-severity category for all route segments. These products are summed and printed in the main output file. The individual probabilities, consequences, and products are also saved and written to supplementary output files (R5INTERM.DAT, R5PLOT0.DAT, R5PLOT1.DAT, and R5PLOT2.DAT), as discussed in Appendix B.

2.2 Terms used in Radioactive-Material Transportation

2.2.1 Package and Packaging

The terms “package” and “packaging” are formally defined in Volume 10 of the Code of Federal Regulations (CFR), Title 71.4 (10 CFR 71.4). Briefly, in radioactive-material transportation, a ***package*** consists of a ***packaging*** and its ***radioactive contents***. A ***packaging*** consists of one or more receptacles and wrappers and their contents, excluding radioactive materials but including absorbent material, spacing structures, thermal insulation, radiation shielding, devices for cooling and absorbing mechanical shock, external fittings, neutron moderators, nonfissible neutron absorbers, and other supplementary equipment. The ***radioactive contents*** may consist of one or more radioactive materials, which are defined in the next section.

2.2.2 Radioactive Materials, Physical-Chemical Forms, Isotopes, and Radionuclides

The ***radioactive contents*** of a package are defined by regulation as ***radioactive material*** (10 CFR 71.4), which is often abbreviated RAM. A radioactive material must contain at least one ***radionuclide***. A ***radionuclide*** is one of two or more atomic forms of an element with the same number of protons, but different numbers of neutrons, in their nuclei. The term ***radionuclide*** refers only to ***unstable*** nuclides that emit ionizing radiation. In practice, the term “isotope,” used alone, is generally taken to mean a radionuclide; a non-radioactive nuclide, however, is generally distinguished by the term “stable nuclide” or “stable isotope.”

The description of a radioactive material (package contents) in a RADTRAN 5 analysis must include a user-assigned name, also referred to as a ***package identifier***. Each material has one or more ***physical-chemical forms***, which are assigned via the constituent isotopes. ***Physical-chemical form*** is a function of
(1) physical properties [i.e., whether the material is a monolithic solid, divided solid (powders of various types), liquid, or gas] and
(2) chemical properties (such as melting point or oxidation state) that might affect dispersion or toxicity in potential accidents.

RADTRAN 5 permits the user to identify one or more physical-chemical forms for each material.

BOX 2-1
PACKAGE IDENTIFIERS, PHYSICAL-CHEMICAL GROUPS, AND NUCLIDES

Examples of Package Identifiers (Material Names) (user assigned):
UO2POWDR for Uranium Dioxide Powder
VHLW for Vitrified High-Level Waste
MOLYGEN for Molybdenum-99 Generator

Examples of Physical-Chemical Group Identifiers (user assigned):
VOLSOL for volatile solids (e.g., radioruthenium)
GAS for gaseous materials such as tritium gas
POWDR1 for a metal oxide such as uranium dioxide with a 1-mm average particle diameter

Examples of Radionuclides and their RADTRAN 5 Identifiers (fixed; user cannot vary)
Uranium-235; identifier is U235
Cesium-137; identifier is CS137
Molybdenum-99; identifier is MO99

Each such form is known as a ***physical-chemical group***, and each must be assigned a ***physical-chemical-group identifier*** as shown in Box 2-1. Each radionuclide in a material must be assigned to at least one group. Properties such as deposition velocity, which depend on physical state (particle size in the case of deposition velocity), are assigned to the physical-chemical group. Photon energy, on the other hand, is a property of atoms and so is assigned to individual nuclides. Physical-chemical properties of materials cannot be supplied in advance by RADTRAN. Most radionuclide properties, however, are supplied in the internal library of radionuclide data (see Chapter 3). The notable exception to this is, of course, the radionuclide inventory, i.e., the amount of each radionuclide that is present in the package. Nuclide identifiers, when entered in the format recognized by the RADTRAN 5 internal library (see box for examples), will cause all recorded nuclide properties to be automatically entered in the input file (Appendix D contains a full list of radionuclide identifiers).

2.2.3 Shipment and Related Terms

2.2.3.1 Shipment, Conveyance, Vehicle, Vessel

A ***shipment*** is defined as the set of all packages in one or more conveyances, traveling together as a unit. A ***conveyance*** is any ***vehicle, vessel***, railcar, or aircraft used to transport packages. Although the term ***vehicle*** generally refers to trucks, vans, etc. for highway-mode transportation, the terms ***vehicle*** and ***conveyance*** are often used interchangeably. The term ***vessel*** refers only to ships and barges for waterway-mode transportation. More than one package of radioactive material may be transported together in a single conveyance. In the rail mode, more than one conveyance may be transported at the same time in a single shipment (i.e., several railcars in a single train).

2.2.3.2 Transportation Mode and Keyword VEHICLE

Commercial transportation involves one or more of the five basic modes: highway, railway, waterway, passenger air, and cargo air. Five variants of highway and two variants of waterway mode have been included in RADTRAN 5 for user convenience. The modes and variants available in RADTRAN 5 are listed in Table 2-1, which also indicates the conveyance types most likely to be used with each mode or variant. The old designators used in previous releases of RADTRAN are included for the convenience of long-time RADTRAN users. Each of the transportation modes and variants available in RADTRAN 5 is assigned a numerical mode-identifier (Table 2-1). Potential operational differences within the rail mode (e.g., the differences between general rail freight and dedicated rail) are addressed with user-assigned variable values discussed elsewhere in this User Guide.

The RADTRAN keyword VEHICLE (keywords are discussed in Chapter 3) identifies the field in which the user enters the name assigned to a conveyance type. The user must create an alphanumeric identifier for each conveyance type in a RADTRAN analysis (e.g., SEMI-TRUCK for a tractor-trailer and DELIVERY for a van) and assign each conveyance type to a mode (see Table 2-1). The user also must enter information associated with the conveyance, such as number of crewmembers. Up to 12 distinct conveyance types may be described in a single RADTRAN 5 run. Each conveyance must be assigned to at least one mode, but assignment variations are permitted since more than one conveyance or mode may be used to get a single package or a shipment to its final destination. When more than one mode is used, the one in which the majority of the transportation occurs is referred to as the ***primary mode***, while others are referred to as ***secondary modes***. A secondary mode is required when material must be moved to its primary-mode conveyance (e.g., an airplane) from its origin point or from the primary mode to its final destination by another vehicle, usually a truck or van.

Table 2-1. RADTRAN 5 Modes and Common Conveyance Types

Mode	Mode Number	Conveyance Types Associated with Mode	Old Name (RADTRAN 4)
HIGHWAY	1	Any truck; usually a tractor-trailer(also called a "semi" or a combination truck)	TRUCK
RAILWAY	2	One or more railcars in a single train	RAIL
WATERWAY_A	3	Any vessel; usually barge	BARGE
WATERWAY_B	4	Any vessel; usually ocean-going ship (>3000 gross tons)	SHIP
CARGO_AIR	5	Any plane carrying only cargo	CARGO_AIR
PASNGR_AIR	6	Any plane carrying passengers & cargo	PASS_AIR
HIGHWAY_A	7	Any truck; usually small truck or passenger van	P_VAN
HIGHWAY_B	8	Any truck; usually cargo van/delivery truck as secondary vehicle with tractor-trailer as primary mode	CVAN_T
HIGHWAY_C	9	Any truck, usually cargo van/delivery truck as secondary vehicle with rail as primary mode	CVAN_R
HIGHWAY_D	10	Any truck; usually cargo van/delivery truck as secondary vehicle with cargo air as primary mode	CVAN-CA

2.2.3.3 Terms Associated with Stops and Handlings

The term ***stop*** refers to any of the various events that may occur in the course of transportation during which a conveyance remains stationary. Most stops are analyzed under keyword STOP. A ***handling*** is a special type of stop that is treated separately in RADTRAN 5 under keyword HANDLING. In all stops, the shipment is modeled as a stationary point- or line-source; the duration of the stop and the number and average distance (or population density) of persons in the vicinity of a stop are problem-specific input parameters. The RADTRAN 5 stop model is highly flexible and can be used to describe most transportation-related stops with little difficulty. Common types of stops modeled under keyword STOP are listed in Box 2-2 and described briefly below:

Box 2-2 - Common Types of Stops

-Rest/Refueling (Highway mode)

-Classification (Rail mode)

-Port Call (Water modes)

Intermodal Transfer (any 2 modes)

Storage (any mode)

■ Rest/Refueling Stops (HIGHWAY Mode). For commercial truck shipments, most stop time is incurred at commercial truck stops. Data for this type of stop have been published (Griego et al., 1996; Madsen and Wilmot, 1983). In the case of delivery vans, especially when used as a secondary mode, the stop time is incurred primarily at traffic stops and at intermediate destinations (when packages are delivered to two or more destinations by the same conveyance).

■ Classification Stops (RAILWAY Mode). The majority of stop time for trains is incurred at classification yards, which may be thought of as “nodes” along the rail network where trains are broken down and reassembled into new trains according to their ultimate destination on the network. Railcars are inspected at classification stops, and rail inspectors may be exposed as a result. Other personnel in the rail yard also would come within various distances of cars carrying radioactive material while performing their duties. Ostmeyer (1986) models this type of stop, and rail worker doses are automatically calculated in RADTRAN 5 according to the Ostmeyer model. However, the stop model is used to assess the area surrounding the classification yard.

■ Port Calls (WATERWAY Modes). Most stop time in maritime modes is incurred in ports either at the dock or in an anchorage. Inspectors from the U.S. Coast Guard, the port authority, and possibly the carrier or shipper, may incur exposure during inspection of packages in the cargo areas. Transportation by ship or barge is nearly always a primary mode used in conjunction with a secondary surface mode. Therefore, exposures incurred during or after loading and offloading a ship or barge fall under the heading of intermodal transfers, which are discussed below.

■ Intermodal Transfers. Packages may be carried part of the way by one mode, removed from the first conveyance, placed in another, and transported all or part of the remaining distance by a second mode. ➨***Each change from one mode to another is defined as an intermodal transfer.*** One or more intermodal transfers may be required to get a package from its origin point to its final destination. For example, carriage of a package by vessel (ship or barge) is usually preceded by carriage by truck or rail from the package’s origin point to a marine port, where the package is loaded onto a vessel (1st intermodal transfer). At the final port of call, the package is usually offloaded to a truck or railcar that carries the package to its final destination (2nd intermodal transfer). Doses to port workers (except handlers) incurred during an intermodal transfer can be calculated with the RADTRAN STOP model (Neuhauser and Weiner, 1992a:b)

■ Storage. Temporary storage may be associated with intermodal transfer. Warehouse employees and other workers may be exposed during storage. Storage is modeled in the same manner as an ordinary stop with appropriate input values, as described by Neuhauser and Weiner (1992a).

2.3 Two Options in Stop Model

A stop can be modeled in two ways as described in Box 2-3. Either radius values and population densities **or** distances and numbers of persons are assigned by the user. RADTRAN 5 allows the user to separately label each stop, although stops also can be treated in an aggregate manner. In the latter case, for example, all fuel stops might be treated as a single stop equal in duration to the sum of the durations of individual stops, with average or bounding values for other parameters.

Box 2-3. Two Ways to Estimate Potentially Exposed Population at a Stop

1. **Population Density within annular area(s) – User specifies population <u>density</u> and <u>two or more</u> radial distances**
2. **Number of Persons at an average radial distance – User specifies <u>number</u> of persons and <u>one</u> radial distance**

2.4 Separate Model for Handling and Inspection

Handlings and inspections are special types of stop-related activities that are treated separately under keyword HANDLING. Handlers and inspectors are routinely located closer to a package or shipment for longer periods of time than most other persons at stops. Thus, they constitute special subgroups of potentially exposed persons for whom dose estimates may be separately calculated (Weiner and Neuhauser, 1992a,b). A line-source method of calculating handling dose is used for all but the smallest packages. Doses for handling the latter are calculated with an empirical factor. As noted in the section on stops, intermodal transfers have characteristics of both a stop and a handling.

Commercial maritime carriers usually plan a sequence of port calls to take on and discharge cargo in the course of a single voyage. Radioactive materials packages that may be onboard would experience stop time at each such intermediate port, but measurable exposure would normally be limited to hold inspectors, and the latter are modeled under keyword HANDLING.

Inspection/Weigh Station stops are often associated with state and national boundary crossings. Trucks and railcars carrying radioactive materials may be required to stop at a state boundary for inspection. Exposure of inspectors located at short distances from the shipment should be modeled with the HANDLING subroutine, while exposure of weigh-station operators and other personnel located at greater distances from the shipment should be considered under the keyword STOP.

3 Creating an Input File for RADTRAN 5

3.1 Access to RADTRAN 5

Users may access RADTRAN 5 by two means. The recommended method is to access the code by modem or the Internet via Sandia National Laboratories' TRANSNET system. The other method is to install an executable version on a UNIX workstation or mainframe computer.

3.1.1 The TRANSNET System

TRANSNET is a collection of risk, systems analysis, routing, and economic codes and related databases pertaining to RAM transportation. TRANSNET resides on a dedicated computer at Sandia National Laboratories. After obtaining a user name and password, users may access TRANSNET at no charge with a personal computer and a modem or an Internet connection. One goal of the TRANSNET system is to transfer technology and data to users who otherwise would not have access to large computational systems of the type required to run RADTRAN and several of the other codes available on TRANSNET.

3.1.2 Executable RADTRAN 5

The second option, running executable RADTRAN code on a workstation or mainframe, has been retained primarily for users who need to deal with classified or high-security information. Executable copies may be obtained by contacting the address shown in Box 3-1. RADTRAN 5 is resident at SNL on a Hewlett-Packard 700 Series computer running with a UNIX operating system. Other systems will also support RADTRAN 5. Details on installing RADTRAN 5 are machine-dependent; directions are provided at the time of request and are not discussed further in this User Guide.

3.2 RADTRAN 5 on TRANSNET

3.2.1 How to Access TRANSNET

Basic hardware and software requirements for accessing TRANSNET are a personal computer, workstation, or other computer, and

- a telephone modem, an Internet Service Provider (ISP), a web browser, and TELNET software;
- <u>Or</u> a network or Ethernet board, a direct cable link to the Internet, and TELNET software

Box 3-1
FOR TRANSNET ACCESS write to:
TRANSNET Operations MS-0718
Attn: Ms. Frances Kanipe
Sandia National Laboratories
PO Box 5800
Albuquerque, NM 87185-0718.
Or fax a request on signed letterhead to:
505-844-0244

A third possibility, access via modem without an ISP and browser, requires another type of specialized communications software (e.g., ProComm Plus 3.0™). A printer is optional but highly recommended. These topics are discussed in the "Guide to TRANSNET Communications and Operations," which is sent to users when they apply for access to the system. Requests should be mailed to the address in Box 3-1. ➨***TRANSNET cannot be accessed without an SNL-issued user name and password.***

The RADTRAN Web Site may be accessed at **http://ttd.sandia.gov/risk/radtran.htm** (case-sensitive). Electronic versions of this User Guide, other code documentation, and up-to-date information regarding persons to contact, etc., are posted at this site.

3.3 RADTRAN 5 Input File Generator Software (RADDOG)

RADTRAN 5 input files may be created on the TRANSNET system by means of user-friendly menus, which are produced by the RADTRAN 5 Input File Generator (RADDOG). RADDOG software is also available on diskette for stand-alone use on a PC, which frees the user from having to be on-line (and possibly paying usage fees) during the sometimes lengthy process of creating an input file. This code is available on request from SNL from the sources listed in this chapter.

The TRANSNET Guide tells the user how to navigate to the TRANSNET RADTRAN Control Menu (Figure 3-1) and from there to the RADDOG Main Menu, which is shown in Figure 3-2. The Work Area of the Main Menu is blank. Twelve headings appear at the top of the Main Menu screen. Each heading except the last represents one or more subordinate menus in which various types of input data are entered.

➨***A <u>Command Line</u> appears at the bottom of every menu screen.*** The text on the command line tells the user what commands may be used for each screen; the blinking cursor following the informational text indicates where typed commands entered by the user will appear. The command line of the Main Menu informs the user that he or she must enter the capitalized letter of a heading in order to bring up the menu screen(s) for that class of data. For example, enter "T" for the stop menu screen.

3.4 Data-Entry Menus

Data-entry menus are subordinate to the RADDOG Main Menu and are reached by typing the appropriate heading letter. For example, typing "P" on the Main Menu command line (no carriage return) brings up the Package screen (Figure 3). The word "Package" is now highlighted on the screen, and column headings for package-related parameters appear in the Work Area. The command line now indicates that the user may enter an "A" (for <u>A</u>dd) to begin entering a row of data. When the user types an "A," the numeral "1" appears in the Row Number column, and the blinking cursor is no longer located on the command line. Instead, it appears following the numeral "1" to indicate that data entry may begin on this row. The user then must enter an alphanumeric package label and appropriate numerical values in the remaining columns in the row. If the user were modifying an existing file, he or she would first enter the number of the row to be modified instead of an "A." When data entry is complete, typing "Q" (for <u>Q</u>uit) returns the cursor to the command line.

Data are entered and modified in the same manner on every screen brought up under each heading at the top of the Main Menu. ➨***The preferred order is to work sequentially from left to right, starting with "Package," because some values that appear in later screens depend on those entered in earlier screens.*** All RADTRAN input parameters are discussed at length in others sections of this Guide.

The penultimate heading is "Comments." Within "Comments," the user may type up to 60 lines of text to indicate the nature of the analysis being performed. ➨***Comment lines document the purpose and pertinent technical details of an input file. They are an excellent quality-assurance and record-keeping tool that the user is strongly encouraged to utilize***. Later sections of this chapter contain information about the types and sources of input data.

3.5 Other Methods of Creating Input Files

TRANSNET users may also create input files with a text editor (e.g., Microsoft™ Editor or Vi™) without using the menus (see discussion under Section 3.3). In fact, after they have gained some experience with the code, TRANSNET users often find that the text-editor method is faster than using the menus.

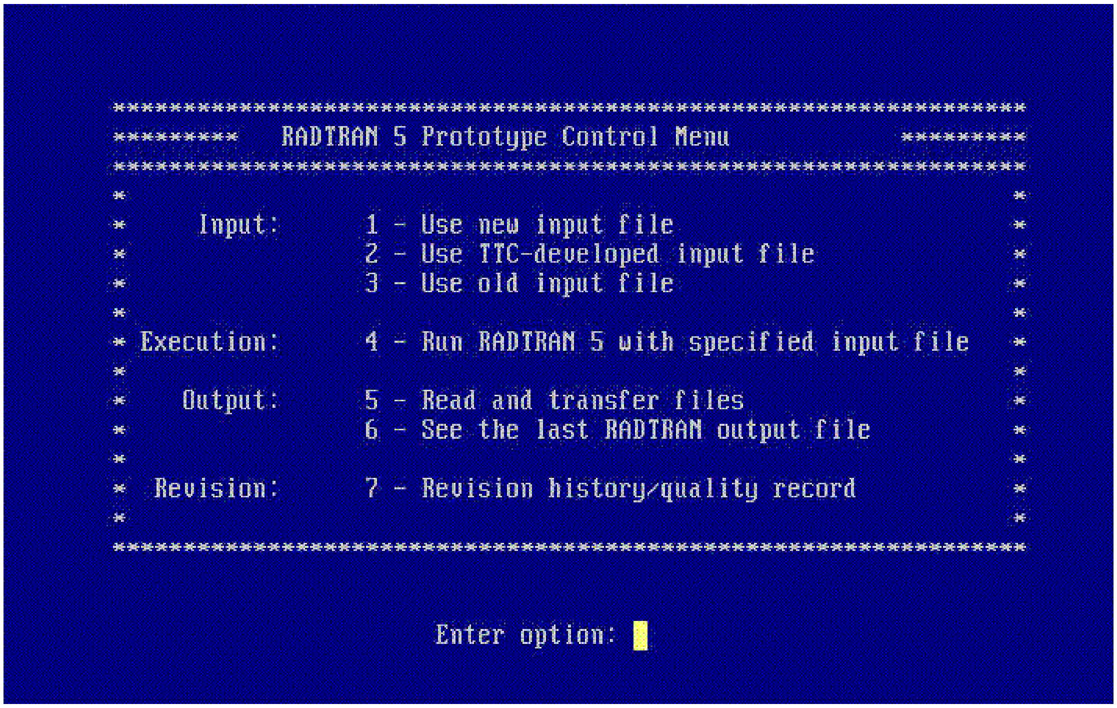

Figure 3-1 TRANSNET Control Menu

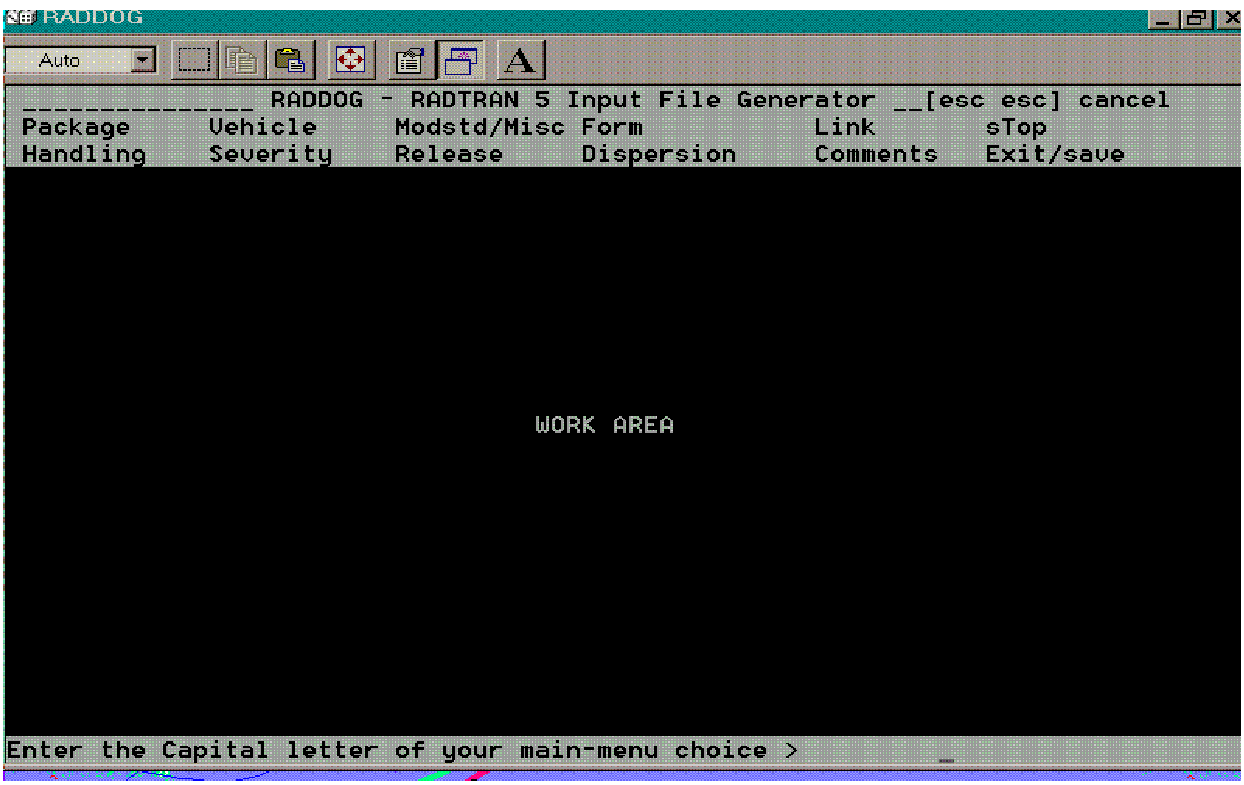

Figure 3-2 RADTRAN 5 Input File Generator Software (RADDOG) - Main Menu Screen

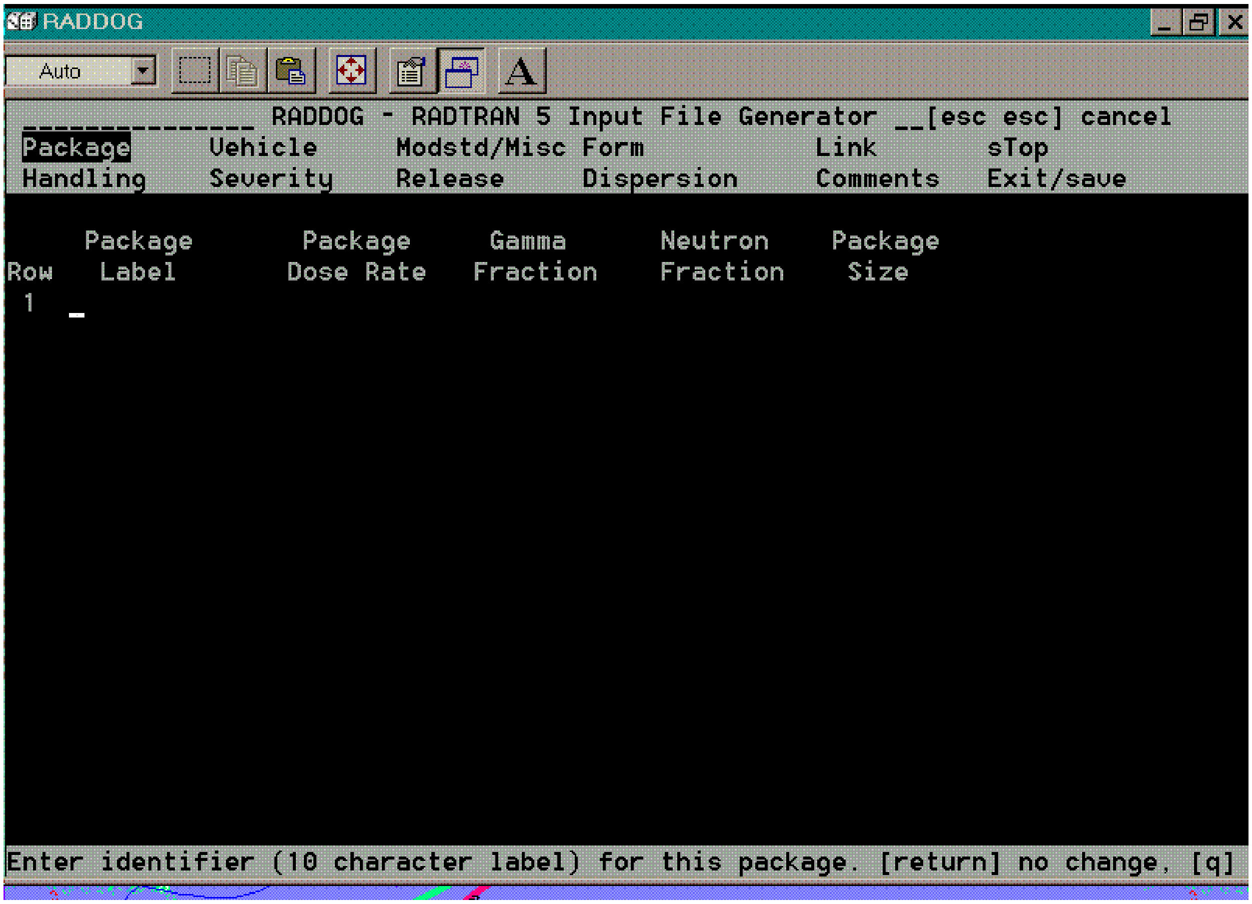

Figure 3-3 RADTRAN 5 Input File Generator Software (RADDOG) - Package Screen

3.6 Running RADTRAN 5 on TRANSNET

When data entry is complete, select the final Main Menu heading, “Exit/save.” This returns the user to TRANSNET’s RADTRAN 5 Control Menu (Figure 3-1); users will be asked to name and save the file. A newly created or modified input file can be saved, named or renamed, and run from this menu. To run RADTRAN, simply select “Run RADTRAN 5 with the indicated input file.” RADTRAN should take only a few moments to run. When the run is complete, the user will see the words SUCCESSFUL COMPLETION on the screen; then the prompt will re-appear.

The name of the main RADTRAN output file is R5OUT.DAT. It can be downloaded, viewed with an editor, renamed, copied, and printed. Regardless of the method used to create an input file, the output will always be in the format described in this chapter and in Chapter 4.

If a run cannot be completed successfully, the message ‘INPUT ERROR’ or the message ‘ERROR - OUTPUT FILE INCOMPLETE’ will appear on the screen. In the former case, the user is advised to examine the input echo in the output file (R5OUT.DAT) to see where execution stopped and then to correct the problem in the input file. In the latter case, the output file (R5OUT.DAT) should contain one or more additional error messages that describe the problem(s). Error messages and suggested correction strategies are listed in Appendix D.

3.7 RADTRAN 5 on a Workstation or Mainframe

3.7.1 Creating an Input File with a Text Editor for Personal Computers

Workstation users may use a text editor to create and edit input files. The first step is to create and name a blank input-data file (e.g., MYFILE.DAT). It should be an ordinary text file and be located in the directory created by the user during installation of RADTRAN 5. ➨ ***Before uploading a new input file for use with TRANSNET, it <u>must</u> have an .IN5 file extension in order for the menus to function properly (e.g., MYFILE.DAT must be renamed MYFILE.IN5 before it is uploaded).*** Any available editor (e.g., Microsoft™ Editor) may be used to create the file. Consult the software manual for the specific editor you are using for necessary instructions. ➨***Data entry in RADTRAN 5 is in free format and is keyword-based.*** The keyword-based system allows most of the data to be entered with any number of intervening spaces or carriage returns. Keywords and data can appear anywhere in an 80-character line. ➨***It is recommended that new users begin by using RADDOG to create a file, if they are not previously familiar with the use of a text editor***. Eventually, the user can graduate to creating with a text editor. In either case, enter data according to the guidance given below. After data entry is complete, the file should be copied and renamed as described previously.

3.7.2 RADTRAN 5 Input File Structure – Fields, Field Values, Delimiters, and Keywords

A RADTRAN input file is an ASCII text file that consists of keywords, numbers, and alphanumeric labels entered as *fields* of ten characters or less which are separated by one or more of the following delimiters: a blank space, comma, equal sign, or right and left parentheses. The term *field value* may refer to a keyword, a number, or a label. Fields may appear anywhere in the 80-character line, but may not be split and continued on the next line. Field values must not contain embedded blanks, commas, equal signs, or parentheses, because these are delimiter characters that denote the end of a field.

A Master List of all keywords is included at the end of this chapter. First-level keywords must be entered before any associated second- and third-level keywords. Following the entry of a first-level keyword and a space, second-level keywords, followed by third-level keywords, may be entered on the same line or the following line(s); each is followed by the required data. A first-level keyword is not always followed by a second- or third-level keyword. As the DIMEN keyword in the Master List illustrates, data may directly follow a first-level keyword, separated by spaces or other delimiters. The "or" separating two keywords in the Master List indicates that the user may enter one of the keywords, but not both, in a single analysis. Finally, the Description column of the Master List briefly describes the type of data to be entered after each keyword and gives the units that must be used. Where an array of numbers must be entered, the array is described in detail in the following text.

Integer data can be entered as real numbers; they will be truncated. Real variables can be entered as integers, in which case they will be converted internally. Entry format can be either exponential (e.g., 9.99E+1, see Box 3-2) or decimal (e.g., 99.9). A special delimiter character, the asterisk [*], may be entered in numeric-array fields to designate a repeat character. For example, to repeat the number 10.1 six times, enter 6*10.1. Blanks cannot separate the numbers and the asterisk delimiter. The asterisk must ***not*** be used in the data for DIMEN or PARM or in any alphanumeric-label field.

Any field consisting of two ampersands (&&) followed by a delimiter (usually a space) causes all subsequent information on that line, regardless of its content, to be entered as a comment line. The use of comment lines is strongly recommended. Examples of the use of comment lines are given in sample files later in this chapter.

Box 3-2 EXPONENTIAL NOTATION

Exponential notation is the most convenient means of writing very large and very small numbers.

For example, the small number 0.00000052 can best be expressed in exponential form. That is, as 5.2E-7. The notation means the number 5.2 is multiplied by the number 10^{-7} (.0000001), which is 10 with the ***exponent*** –7.

Exponential notation may be used to express any number in RADTRAN 5. It **must** be used to enter numbers with more than 10 characters.

Special keywords that are never followed by data are also noted in the Master List. They are EOF (End of File), EOI (End of Input), and END (marks end of data entry for keyword PACKAGE).

3.7.3 Getting Started

To begin building a data set, five first-level keywords are usually entered: TITLE, INPUT, FORM, DIMEN, and PARM. ➡**TITLE, INPUT, FORM,** ***and*** **DIMEN** ***are always entered***. Pre-assigned values are available for PARM; therefore, this keyword is only entered if the user does not wish to accept the pre-assigned values. Each of these keywords is discussed below.

TITLE. The first input line must be a title record. The line must begin with the keyword TITLE followed by at least one space. Since entry is on an 80-character line and since fields may not be continued on a second line, this means that the actual letter count of a user-assigned title may not exceed 74 alphanumeric characters in length. The user will find that it pays to develop as descriptive a title as possible.

INPUT. The second line of the input file must start with the keyword INPUT followed by either the keyword STANDARD or the keyword ZERO. STANDARD will bring up pre-assigned values for several RADTRAN 5 parameters; these are mainly parameters with values that are seldom altered (e.g., breathing rate, building shielding factors). ZERO initializes all input-data values to zero. The user then must enter specific values for the parameters under keywords MODSTD and FLAGS, which are described later in this section.

DIMEN. Three ordered numeric fields each separated by a delimiter (see Box 3-3) must follow DIMEN. They specify the dimensions of the following arrays:

Box 3-3 DIMEN Line Example

```
DIMEN   6 10 18
```

- NSEV Field. The number of accident-severity categories that will be used in the analysis (maximum = 30);
- NRADIAL Field. The number of radial distances to be used in nondispersal accident analysis (maximum = 15);
- NISOPLETH Field. The number of downwind dose and deposition areas to be used in dispersal accident analysis (maximum = 30).

FORM. The third line of the input file must start with the keyword FORM followed by at least one space and either UNIT or NONUNIT (second-level keywords). This determines the form of the output: either UNIT for population dose or NONUNIT for health effects. Two runs with an otherwise identical input file are required to obtain both types of output.

PARM. With PARM, the user selects settings for four flags, which in turn control certain code functions. The flags, in order of entry, are:

- The plot flag for placing data in output files for probability-consequence plots; the STANDARD value is yes (1); to not produce those files, set flag to zero.
- The selection flag with which the user selects incident-free analysis (1), accident analysis (2), or both (3); the STANDARD value is both (=3);
- The output flag for choosing the level of output; the STANDARD value is the full output (3). If set to 1, a short summary is printed; if set to 2, the output contains more detailed tables of results; if set to 3, all input data, results, and importance rankings are shown in table form.
- The Pasquill flag for selecting Pasquill stability categories (1) or user-supplied time-integrated concentration isopleths and areas (0); the STANDARD value is zero.

If the user wishes to alter the settings of *any* of the flags subordinate to PARM, the keyword PARM should be entered and followed by four numbers indicating the new settings. If the user omits PARM, then the standard settings for all flags are used.

3.7.4 Flags

In addition to the flags already discussed under keyword PARM, four flags are set under the keyword FLAGS and one additional flag is associated with the keyword VEHICLE.
They are described in this section.

Flags under Keyword FLAGS

1. IACC. The standard value for the IACC flag is 2. This setting directs the code to work through all exposure pathways associated with atmospheric dispersal of package contents during an accident. The alternative value of IACC = 1, denotes non-dispersal and is used to examine particular scenarios such as loss-of-shielding or accidents involving non-dispersible package contents (also called “special form” materials).

2. ITRAIN. This flag, used only for rail mode, denotes whether shipment is by general freight (ITRAIN = 1) or by dedicated rail (ITRAIN = 2). The standard setting is 1. The main difference between the two options is the exposures of rail workers in railyards. The rail-worker dose is the weighted sum of the doses for all close-proximity rail-worker groups. The doses are calculated primarily with a line-source model. Occasionally a point-source model for worker groups that are consistently present but are somewhat distant from the RAM car(s). For general freight, dose is calculated with the modifying factors b_1 through b_7, which have units of person-hr/km and are derived from Wooden (1987) as described in Appendix B of the RADTRAN 5 Technical Manual (Neuhauser, Kanipe, and Weiner, 2000). For dedicated rail, worker dose is calculated with factors b_8 through b_{11}. If no rail-mode transportation is to be analyzed, then the flag setting is ignored.

3. IUOPT. This flag is used to select a building shielding option. For the STANDARD value (IUOPT = 2), persons in buildings are exposed at reduced rates and the reduction in dose rate is a function of the shielding factors RR, RS, and RU, which are described later in this chapter. Setting the IUOPT flag to 1 (full shielding) is equivalent to setting all shielding factors to zero (everyone indoors is fully shielded and receives no dose), which can be used to separately examine impacts to persons out of doors. Setting the IUOPT flag to 3 is equivalent to setting all shielding factors to 1.0 (being indoors provides no protection and is the same as being outdoors). The last option is too conservative to be generally applied, but it may be useful for comparative studies. ➨***If the STANDARD setting is accepted, the user may still separately alter the values of the individual shielding factors***.

4. REGCHECK. The STANDARD setting is REGCHECK = 1, which causes a series of regulatory checks to be performed. If any circumstances are identified that violate the regulatory requirements (e.g., package dose rate exceeds regulatory maximum), then the appropriate parameter values are reset to the regulatory maximum and the calculation continues. A message informing the user is printed in the output. The user may also set REGCHECK = 0, which bypasses the regulatory-check subroutine. This flag setting can be useful for analysis of a shipment operating under waivers of various types (e.g., certain radiopharmaceutical shipments (Finley, McClure and Reardon, 1988)).

Exclusive-Use Flag

An exclusive-use shipment is a shipment that carries only radioactive-material packages and no other cargo. Exclusive use is denoted by placing a negative sign in front of the mode designator in the VEHICLE array. In the absence of a negative sign, the shipment is considered non-exclusive-use for regulatory check purposes. There can be no STANDARD value for this flag, since the correct setting is problem-dependent

3.7.5 The Remainder of the Input File

After TITLE, INPUT, FORM, DIMEN (and sometimes PARM) have been entered, most other keywords may follow in any order with two exceptions:

- a package must be described before it can be associated with a vehicle;
- a vehicle must be described before it can be associated with a LINK; and
- a nonstandard isotope (i.e., one described under keyword DEFINE) must be described before the assigned isotope can be associated with a material or a package.

All parameters are described in detail in Sections 3.4 through 3.6. The hierarchical relationship between the keywords also must be observed. After a keyword is entered, data arrays of the proper size are entered (array sizes are indicated in Table 2).

If STANDARD was entered after keyword INPUT, then the user must enter values for:

- all parameters without STANDARD values; and
- any parameters with STANDARD values that the user wishes to change for the problem being analyzed.

Unlike the RADDOG screens, a text editor cannot show the user the STANDARD values. Users creating input files with text editors should consult the list in this User Guide.

If ZERO was entered after keyword INPUT, then no STANDARD values are accepted and the user must enter values for every required parameter in the input file. ➨***Altering the STANDARD value of a parameter not used in the calculation has no effect on the results.*** For example, altering the value for number of flight attendants will have no effect if the user is analyzing a rail shipment since the parameter is not used in any rail-related calculations in RADTRAN.

The keyword EOF must appear before values entered with LINK, STOP, and HANDLING are entered but after all other data have been entered. The keyword EOI must be entered on the last line of the input file.

3.8 Running RADTRAN 5 on a Workstation

In order to run RADTRAN5 on a workstation, an input file, which is an ordinary text file, must be created and named R5IN.DAT. The output file is always initially named R5OUT.DAT. When dealing with many separate input files, which have been saved under other filenames, it is best to copy one file at a time just before beginning to run each one. The corresponding output file also should be renamed at once, as described in the following section.

To begin a run with the properly named input file, type the name of the executable RADTRAN 5 file, usually “rt5.” The code should take only a few moments to run. When the run is complete, the user will see the words SUCCESSFUL COMPLETION on the screen; then the prompt will appear. The name of the main RADTRAN output file is R5OUT.DAT. It can be printed, viewed with an editor, renamed, or copied.

If a run cannot be completed successfully, the message ‘INPUT ERROR’ or the message ‘ERROR – OUTPUT FILE INCOMPLETE’ will appear on the screen. In the former case, the user is advised to examine the input echo in the output file (R5OUT.DAT) to see where execution stopped and then to correct the problem in the input file. In the latter case, the output file (R5OUT.DAT) should contain one or more additional error messages that describe the problem(s). Error messages and suggested correction strategies are listed in Appendix D.

3.9 Saving Output Files on a Workstation

If the user wishes to save an output file, then the file must be copied and renamed. Otherwise, the file will be overwritten after subsequent runs. Workstation users must remember to do this themselves; they will not be prompted as TRANSNET users are. The user also should be aware that additional output files are generated for each run which are not normally displayed but which the user may wish to save. They contain the probability-consequence data pairs used in accident-risk calculations. These data also may be used to generate tabular or graphic displays of probability-consequence relationships, as discussed in Appendix C. The output files are:

- R5INTERM.DAT, which contains unsorted intermediate data.
- R5PLOT0 .DAT, which contains the sorted dose (person-rem) or latent cancer fatality consequences with summed probabilities;
- R5PLOT1.DAT, which contains the sorted genetic effects consequences with summed probabilities; and
- R5PLOT2.DAT, which contains maximum individual doses with summed probabilities.

· INGVAL.OUT, which contains the raw output data from COMIDA2 for ingestion dose calculation.
These files must be separately copied and renamed if the user wishes to save them as well.

3.10 Problem-Specific Input Parameters

This section discusses parameters for which STANDARD values cannot be developed. They include package- and vehicle-specific parameters, plus certain route-specific parameters.

3.10.1 Package-Specific Parameters

Since it is impossible to predict in advance what combination(s) of packaging and contents will be analyzed, all package-specific parameters must be provided by the user. Values for the following five parameters are entered after the keyword PACKAGE (Box 3-4).

1. Alphanumeric identifier, up to ten characters in length (e.g., SPENTFUEL)
2. Package dose rate 1 m from surface of package (mrem/hr)
3. Fraction of dose rate that is gamma radiation
4. Fraction of dose rate that is neutron radiation
5. Characteristic Package Dimension (m) [assignment of characteristic package dimension is discussed in Chapter 4]

A list of the isotopes in a package must appear below the PACKAGE line. Data for each isotope must be entered on a separate line. Three pieces of information, each separated by a space must appear on each isotope line. They are:

1. Isotope name in required format
2. Amount of the isotope in the package (Ci)
3. Identifier for physical-chemical group to which the isotope is assigned (e.g., VOLATILE)

The isotope list must be terminated by the keyword END as shown in Box 3-4 and as illustrated in Figure 1

Box 3-4 Example of Data Entry under Keyword PACKAGE

```
PACKAGE  SPENTFUEL  1.368E+001  1.000 0.000  5.20
        CO60      9.220E+001 COBALT
        KR85      6.100E+003 NOBLE
        SR90      5.960E+004 ACT_OTHERS
        RU106     1.620E+004 RUTHENIUM
        CS134     2.740E+004 VOLATILE
        CS137     8.760E+004 VOLATILE
        CE144     1.220E+004 CE_EU
        EU154     7.000E+003 CE_EU
        PU238     2.960E+003 ACT_OTHERS
        PU239     4.100E+002 ACT_OTHERS
        PU240     4.680E+002 ACT_OTHERS
        PU241     1.260E+005 ACT_OTHERS
        AM241     1.290E+003 ACT_OTHERS
        AM243     1.990E+001 ACT_OTHERS
        CM244     1.790E+003 ACT_OTHERS
        END
```

3.10.2 Vehicle-Specific Parameters

The following are entered following the keyword VEHICLE:

- Mode number (see Chapter 2) modified by the Exclusive-Use Flag (a negative sign) if necessary (see Section 3.3.1.3).
- Alphanumeric vehicle identifier, up to 10 characters in length (e.g., PHARM_1).
- Dose rate at one meter from the surface of the vehicle (mrem/hr)
- Fraction of dose rate that is gamma radiation
- Fraction of dose rate that is neutron radiation
- Characteristic vehicle dimension (m)
- Number of shipments to be carried out in the specified vehicle type
- Number of crew members
- Average distance (m) of crew members from the geometric center(s) of one or more radioactive-material package(s)
- Crew Modification Factor, a fractional multiplier that can be used to account for mitigating factors such as shielded crew cabs in semi-trucks. If there are no such mitigating factors then the Crew Modification Factor should be set to unity.
- Crew View Package Dimension (m), which accounts for situations in which the regular Characteristic Package Dimension (e.g., the length of a cylinder) would overestimate dose rate to crew compartment (in the example, the diameter of the cylinder would give a better estimate). This is discussed more fully in Chapter 5.

The VEHICLE line must be followed by any package identifiers (alphanumeric identifiers that the user creates under keyword PACKAGE), which indicate what kinds of packages are carried in the specified conveyance. Each package type is listed on a separate line; the package identifier is followed by at least one space and a numeral indicating the number of packages of that type being carried in the vehicle. In the example in Box 3-5, four packages of type PHARM_1 and five packages of type PHARM_2 are being carried by non-exclusive-use highway mode in a vehicle identified as VAN. The vehicle (VAN) has a maximum dose rate of 1.9 mrem/h (measured at 1 meter from the side of the van) that is 100% gamma radiation and 0% neutron radiation. The remaining values tell us that:

- the van is 3.5 m in length;
- one (1) shipment is being analyzed;
- there is one (1) crew member (driver),
- who averages a distance of 2.0 m from the packages,
- who is unshielded (i.e., the cab has a shielding factor of 1.0),
- and who is exposed, in this case, to a close-packed array of packages with an overall characteristic dimension of 1.5 m.

Box 3-5 Example of Data Entry under Keyword VEHICLE

```
VEHICLE 1 VAN 1.9 1.0 0.0 3.5 1 1 2.0 1.0 1.5
 PHARM_1  4
 PHARM_2  5
```

3.10.3 Route-Specific Parameters

The remaining problem-specific parameters describe the route(s) that the shipment(s) being analyzed will traverse. The majority of these are entered under the keywords LINK, STOP, and HANDLING. Each is discussed in detail in Chapter 5.

3.10.3.1 Keyword LINK

Following the keyword LINK, an array of twelve parameters is entered for each route-segment. Each route-segment array must be on a separate line. ➡Two of the parameters, fraction of land under cultivation and vehicle occupancy, are new to the LINK array. The full array now is:

- Alphanumeric Segment Identifier (user-defined)
- Vehicle Identifier (previously defined; see Section 3.4.2)

- Segment length (km)
- Velocity (m/s)
- Vehicle occupancy (persons/vehicle)
- Population density (persons/km^2) of area surrounding route segment
- Vehicle density (persons/vehicle)
- Accident rate (accidents/vehicle-km)
- Segment character (R=rural, S=suburban, U=urban)
- Segment type (1=interstate; 2 = non-interstate; 3 = any other mode)
- Fraction of land under cultivation.

3.10.3.2 Keyword STOP

Following the keyword STOP, an array of seven parameters is entered.
Each stop must be described on a separate line. The stop parameter array is:

- Alphanumeric Stop identifier, up to 10 characters (user defined)
- Vehicle Identifier (previously defined)
  - Option #1 - Population Density (persons/km^2) **<u>or</u>** Option #2 - Number of Persons
  - Minimum Radius of Annular Area
  - Maximum Radius of Annular Area (set equal to minimum to indicate Option #2)
  - Shielding Fraction
- Stop Time (hr).

3.10.3.3 Keyword HANDLING

Following the keyword HANDLING, an array of five parameters is entered.
Each handling must be described on a separate line. The handling parameter array is:

- Alphanumeric Handling identifier, up to 10 characters (user-defined);
- Vehicle identifier (previously defined);
- Number of handlers;
- Average source-to-handler distance (m);
- Handling time per package (hr/package).

3.11 Radionuclide Data

Pre-calculated values of ten isotope-specific parameters are available for 60 commonly encountered isotopes in an internal database in RADTRAN 5. The values are based on the radiation risk approach in ICRP Publication 26 et seq. (ICRP, 1977, 1979-1982, 1984, and 1986) as updated in BEIR V (NAS/NRC, 1990). The doses are total effective dose equivalents, which are sums of the effective dose equivalents for external exposures and committed effective dose equivalents (CEDEs) for internal exposures and are presented in units of rem (roentgen equivalent man). The user is not required to accept these data and may alter any or all of the values (but not the units) by means of the DEFINE keyword.

ICRP Publications 60 and 68 (ICRP, 1991, 1994) use modified organ weighting, express total effective dose equivalent as effective dose, and express CEDE as equivalent dose. The ICRP findings, when adjusted for low-dose and low-dose rate, yield nearly the same total risk factor for fatal cancer as BEIR V (1990). Although “there is much uncertainty and a certain arbitrariness in the determination of the distribution of fatal cancer probability among tissues and organs,” [ICRP Publication 60 (p. 123)], the same source notes that “The total risk of fatal cancer, on the other hand is comparatively robust.”

In both models the dose-effect relationship conforms to the linear, no-threshold “hypothesis” (LNTH) Use of the LNTH has the advantages of mathematical simplicity and acceptability for demonstrations of regulatory compliance, but effects at low doses are overestimated, possibly to a significant degree. Thus, fatal cancer estimates derived from both models are acceptable and conservative, especially for the rather low doses typically associated with potential transportation-related exposures. ➡ICRP

Publication 60 also recommends using a larger particle size than ICRP Publication 26 et seq. This refinement has not been implemented, but it is anticipated that it will be included in a later release of RADTRAN 5.

In previous releases of RADTRAN, 1-year organ doses attributable to the inhalation pathway were calculated for lung, marrow, gonads, and thyroid (radioiodines only). The results were used to estimate early effects. In order to achieve the early-effects threshold for the gonads (7 rem), however, a receptor would have to inhale many curies of any of the commonly encountered radionuclides. Threshold dose to the most sensitive organ, bone marrow, would usually be exceeded at inhalation levels well below what is required to reach this gonad threshold. Thyroid doses from radioiodine inhalation, however, can be significant even if relatively small amounts are inhaled. For these reasons, early effects continue to be estimated for inhalation-pathway doses to the lung, marrow, and thyroid, but gonad dose calculation is omitted.

3.11.1 Structure of the RADTRAN 5 Radionuclide Library

The RADTRAN 5 radionuclide library contains values for:

1. Half-life (days)
2. Photon energy (MeV/disintegration)
3. Cloudshine dose factor (rem-m^3/Ci-sec)
4. Groundshine dose factor (rem-m^2/μCi-day)
5. 50-yr committed effective dose equivalent for inhalation (rem/Ci inhaled)
6. 50-yr committed effective gonad dose for inhalation (rem/Ci inhaled)
7. Lung type for early-effects calculations
8. 1-yr lung dose for inhalation (rem/Ci inhaled)
9. 1-yr marrow dose for inhalation (rem/Ci inhaled)
10. Alphanumeric identifier for ingestion model

Each parameter is defined and discussed briefly below. Isotopes that receive special treatment are also identified. The entire radionuclide-data library is printed in Appendix E

<u>Half-life</u>. In RADTRAN 5, the unit for half-life is days. All values are taken from ICRP Publication 38 (ICRP, 1983).

<u>Photon Energy</u>. The energy value of photons emitted by an isotope is used to calculate groundshine dose for that isotope. The units are million electron volts (MeV)/disintegration. All values are taken from ICRP Publication 38 (ICRP, 1983). To simplify the analysis, each decay, regardless of whether it is a single photon or a cascade, is treated as a single photon decay with an energy equal to the difference between the initial and ground states of the radionuclide. The values given are derived from the column titled "y(i)xE(i)" (i.e., the average energy emitted per transformation) in Section 3 of ICRP Publication 38.

Photons emitted by short-lived daughter products (half-life less than a few hours) of certain isotopes have been added to the nominal photon energy (if any) of the parent isotope, but the half-life of the daughter is neglected. In other words, the parent isotope is treated as though every transformation produced a photon equal in energy to that of the parent (if any) plus that of the daughter. This approach was used only for isotopes that have half-lives that are large in comparison with the half-lives of the daughter nuclides; this gives a conservative value for photon energy for the analyses performed by RADTRAN 5 without complex calculations. In cases where the daughters are gamma emitters while the parent nuclides are not, potentially important sources of gamma radiation are adequately accounted for with this approach.

Isotopes for which short-lived daughter decays have been included are the following:

- molybdenum-99, which has a daughter, technetium-99m (87.6 percent yield), with a half-life of 6 hr and a photon energy of 1.26E-01 MeV/transformation;
- ruthenium-103, which has a daughter, rhodium-103m (99.7 percent yield), with a half-life of 56 min and a photon energy of 1.75E-03 MeV/transformation;
- ruthenium-106, which has a daughter, rhodium-106 (100 percent yield), with a half-life of 29.9 sec and a photon energy of 2.01E-01 MeV/transformation;
- cesium-137, which has a daughter, barium-137m (94.6 percent yield), with a half-life of 2.6 min and a photon energy of 5.96E-01 MeV/transformation; and
- cerium-144, which has a daughter, praseodymium-144 (98.2 percent yield), with a half-life of 17.3 min and a photon energy of 3.18E-02 MeV/transformation. The remainder of the yield is also a short-lived isotope, praseodymium-144m, but its photon energy is very low and is neglected here.

Cloud Dose Factor. The units of this parameter are rem-m^3/Ci-sec. This factor is the effective dose-rate factor for immersion in air uniformly contaminated with the specified isotope, and it is used to calculate cloudshine dose. All values were taken from DOE-0070 (DOE, 1988a) and converted from mrem-m^3/μCi-yr to rem-m^3/Ci-sec.

Groundshine Dose Factor. The units of this parameter are rem-m^2/μCi-day. This factor describes the effective dose rate 1 meter above a uniformly contaminated plane surface. All values are taken from Federal Guidance Report 12 (EPA, 1993). No credit is taken for surface roughness.

Committed Effective Dose Equivalent for Inhalation. This parameter describes long-term whole-body internal radiation dose (50-yr-dose commitment) resulting from inhalation of respirable aerosol particles of each isotope. Units are rem/Ci of respirable aerosol inhaled. Most values are for 0.3 micron AMAD (activity median aerodynamic diameter) particle size, calculated with the equations in Section 1.2.2 of DOE-0071 (DOE, 1988b), which was also the source of values for this parameter (for the highest lung retention class for each isotope).

The activity mean aerodynamic diameter (AMAD) of 0.3 micron was selected for a specific reason. A population of aerosol particles of plutonium or other dense material with an AMAD of 0.3 micron has a particle-size distribution such that virtually all the particles could lodge in the pulmonary region of the lung (i.e., are less than 10microns and greater than 0.1 micron in diameter) (ICRP, 1977). This particle-size assumption was considered somewhat conservative for dense materials such as uranium, plutonium, other transuranics, and spent-fuel particulates. Since they are also among the most frequently analyzed materials, 0.3-micron AMAD values were used for the internal library data. The newest ICRP model, however, no longer supports use of such low AMADs, and future inhalation dose factors will be calculated on the basis of 1 micron AMAD particles, the minimum now recommended by the ICRP (ICRP, 1994, p.3). The user may redefine an isotope already in the library for a new particle-size distribution by use of the DEFINE function of RADTRAN 5.

Particle size is not a factor for those radionuclides that would be in the gaseous state if released: tritium gas (H3GAS), carbon-14 dioxide gas (C14GAS), and the noble gases. A 1.0-micron AMAD particle size was assigned to two additional materials in the database: tritiated water (H3WTR) and organic forms of carbon-14 (C14ORG). The former would be in vapor or microdroplet form; and the latter usually would be in soot or particulate form.

Committed Effective Dose to Gonads for Inhalation. This parameter describes long-term organ dose (50-yr-dose commitment) to the gonads resulting from inhalation of respirable aerosol particles of an isotope. Units are rem/Ci of respirable aerosol inhaled. The value is used in calculation of genetic effects.

Lung Type for Early Effects Calculations. Lung Type designators are no longer used in RADTRAN 5, but the variable still appears in this array. It will be removed completely in the next revision of RADTRAN.

One-Year Lung Dose for Inhalation. The units are rem/Ci inhaled. This parameter describes the 1-yr committed dose to the lung from inhalation of respirable aerosol of a given isotope. It is used to calculate early fatalities and early morbidities. The values are taken from Dunning (1983) for the highest lung retention class for which values were given for each isotope.

One-Year Marrow Dose for Inhalation. The units are rem/Ci inhaled. This parameter describes the 1-yr committed dose to bone marrow from inhalation of respirable aerosol of the given isotope. It is used to calculate early fatalities and early morbidities. The values were taken from Dunning (1983) for the highest lung retention class for which values were given for each isotope.

Identifier for Ingestion-Dose Calculation. This identifies the isotope for the ingestion-dose calculations. COMIDA-derived dose factors (person-Sv/m^2 and Sv/m^2) are converted to person-rem/m^2 and rem/m^2 and are used to calculate ingestion doses.

3.11.2 Radionuclide Names and Values and the DEFINE option

To analyze a package containing nuclides not found in the internal library, the user must employ the DEFINE capability of RADTRAN 5 to add new nuclides to the internal library. The DEFINE capability may also be used to define (1) two or more physical-chemical forms of the same radionuclide and (2) composite "radionuclides" that are weighted-averages of several radionuclides. The latter approach has been used in the past, to simplify a problem, but is of mainly historical interest today.

➨***Isotope names must be in standardized format to call the proper values for half-life, photon energy, etc. from the internal radionuclide-data library.*** The standard names of all isotopes available in the internal library are listed in Table 4-2. Users always have the option of defining isotopes; the only restriction on names assigned to user-defined isotopes is that they may not exceed 10 alphanumeric characters.

3.12 MODSTD Data for Incident-Free Dose Calculation by Mode

STANDARD values are available for a large number of input variables used in incident-free dose calculations. They are listed under the first-level keyword MODSTD (see Table 3-2). They also are listed on the "Modstd" menu screens in TRANSNET and the stand-alone RADDOG input-file generator software. Table 2 shows the data in the MODSTD array and gives the associated second-level keywords for workstation users. The user may accept none, some, or all of the STANDARD values. The input variables and their values are listed and described in this next section

ADJACENT See DISTON

CAMPAIGN This keyword specifies the duration of the shipping campaign in years. The value calculated with CAMPAIGN is the total number of off-link persons exposed. This result may be used to perform external calculations of annual off-link dose. Annual dose values may be compared with total dose in multi-year shipping campaigns and are useful for assessing regulatory compliance with standards based on annual doses. The STANDARD value is 1.0 year, meaning a period of 365.25 consecutive days.

DDRWEF This keyword applies to rail mode only and specifies the Distance Dependent Rail Worker Exposure Factor. This factor is used to calculate the component of rail-worker dose that depends on distance traveled (e.g., exposure related to engine changes, crew shift-changes, etc., while en route). The STANDARD value of 0.0018 inspections/km is taken from Ostmeyer (1986).

DISTOFF This keyword specifies a set of three distances, in meters, used in off-link dose calculations for highway, rail, and barge modes. The three distances are: (1) the minimum perpendicular distance over which the off-link dose calculation will be integrated; (2) the minimum pedestrian-walkway width, for instances in which dose to pedestrians beside the link is calculated (see RPD for discussion of pedestrian density); and (3) the maximum perpendicular distance over which the off-link dose calculation will be integrated. DISTOFF must be followed one or more keywords that specify values for various link types. The STANDARD values, which are supplied for each link type, are from NUREG-0170 (NRC, 1977). The link types and values for each are:
FREEWAY Any limited-access divided highway. [30, 30, 800]
SECONDARY Any non-limited-access highway that is not a city street (27, 30, 800)
STREET Any city street. [5, 8, 800]
RAIL Any rail right-of-way in the U.S. [30, 30, 800]
WATER Any vessel. [200,200,800]

Note that the values are the same for FREEWAY and RAIL. Setting the first two values equal to each other is equivalent to a sidewalk width of zero and means there are no sidewalks or similar close-in areas where unshielded persons (pedestrians, bicyclists, etc.) may reasonably be expected to be found. For STREET, the sidewalk is modeled as being 3 m wide (Finley et al. 1980). The values for WATER conservatively model a narrow navigable waterway (e.g., Houston Ship Channel) and are taken from NUREG-0170 (NRC, 1977). The WATER values are the ones most likely to require modification by the user since other bodies of water that might be modeled have ship-to-shore distances that greatly exceed 200 m and even 800 m.

DISTON This keyword specifies a perpendicular distance (i.e., a distance measured along a line at right angles to the line of travel of the RAM shipment) between the RAM shipment and other traffic lanes, in meters. For three link types, DISTON represents the *average* perpendicular distance between the shipment *centerline* and the *centerline* of oncoming traffic lanes(s). In the passing-vehicle case, DISTON represents the distance between the shipment *centerline* and the *centerline* of adjacent passing vehicles (HIGHWAY mode only). DISTON must be followed by a second keyword that specifies the link type. The STANDARD values in parentheses in the following list are taken from Madsen et al. (1986, p. 36-37).
FREEWAY Any limited-access, divided highway [15.0 m];
SECONDARY Any non-limited access highway [3 m];STREET Any city street [3 m];
RAIL Any rail right-of-way [3 m].
An additional parameter for highway mode only is ADJACENT It represents the minimum perpendicular distance between shipment centerline and centerline of adjacent passing vehicles [4 m].

The FREEWAY value is based on the Madsen et al. (1986) model of a minimal Interstate configuration of 4 lanes with an average lane width of 5 m, in the most typical traffic configuration. The latter refers to the RAM shipment being in the outside lane, oncoming traffic in the corresponding outside lane, and passing vehicles in the inner lanes. The SECONDARY and STREET values are smaller because these roadways are modeled as being only 2 lanes wide with an average lane width of 3 m. The RAIL value is based on the minimum clearance between passing trains on double rail segments. The ADJACENT value represents the median value for all Interstate and secondary-road lane widths.

FMINCL This keyword is applied to rail mode only and specifies the minimum number of railcar classifications or inspections per one-way trip. The STANDARD value is 2 since there are always at least two inspections per one-way trip - one at the beginning and one at the end of each trip (Wooden, 1986).

FNOATT This parameter is applied to passenger-air mode only and specifies the Number of Flight Attendants. The STANDARD value is 4 (NRC, 1977).

FREEWAY See DISTOFF and DISTON

MITDDIST This parameter is used to calculate the maximum individual "in-transit" dose to a member of the public; it represents the minimum perpendicular distance, in meters, from the shipment centerline to an individual standing beside the road or railroad while a shipment passes. The STANDARD value is 30.0 m (NRC, 1977).

MITDVEL This parameter is used to calculate the maximum individual "in-transit" dose; it represents the minimum velocity, in km/hr, of a shipment. The STANDARD value is 24.0 km/hr (15 mph) (NRC, 1977).

RAIL See DISTOFF and DISTON

RPD This parameter is the Ratio of Pedestrian Density. It is used to calculate the density of unshielded persons on sidewalks and elsewhere in urban areas when the IUOPT Flag is not equal to 3 by indexing it to the population density of the surrounding area. RPD is also used in the calculation of accident consequences. The STANDARD is 6.0, which is based on empirical data from New York City (Finley, 1980). It means that the pedestrian density is six times the residential population density. This figure is likely to be conservative for most other urban areas, but similar data are seldom collected in other cities.

RR This parameter specifies the Rural Shielding Factor. The STANDARD value is 1.0 (i.e., no shielding). Although even wood-frame construction provides some shielding, the Rural Shielding Factor is set to 1.0 to conservatively account for the fact that rural economies involve a relatively large fraction of outdoor employment (farming, ranching, etc.). RR is used in incident-free dose and in dose-risk calculation for non-dispersal accidents.
RS This parameter specifies the Suburban Shielding Factor. The STANDARD value is 0.87, which represents a residential structure of wood-frame construction (Taylor and Daniel, 1982, p.12). RS is used in incident-free dose and in dose-risk calculations for non-dispersal accidents.

RU This parameter specifies the Urban Shielding Factor. The STANDARD value is 0.018, which represents an urban commercial building constructed of concrete block (Taylor and Daniel, 1982, p.12). RU is used in incident-free dose and in dose-risk calculations for non-dispersal accidents.

SECONDARY See DISTOFF and DISTON

SMALLPKG This parameter specifies the first Package Size Threshold. This parameter is used to determine the handling method that will be used for a package, which, in turn, is used in the calculation of handler dose. If a package is designated as "small" then an empirical algorithm for handling dose is used; if package dimensions exceed the threshold then another method is used. The STANDARD value for SMALLPKG is 0.5 m (Javitz, 1985). Although it is highly unlikely that this value will need to be altered, the user has the option to do so.

STREET See DISTOFF and DISTON

3.13 Data for Accident Risk Calculation by Mode and Material Type

3.13.1 Introduction to STANDARD Values for Accident Risk Analysis

➨***The most important arrays in accident-risk calculation do not have STANDARD values***. They are:

- accident-severity fractions (keyword SEVERITY),
- shielding degradation fractions (keyword LOS)
- release fractions (second-level keyword RFRAC under keyword RELEASE),
- aerosol fractions (second-level keyword AERSOL under keyword RELEASE), and
- respirable fractions (second-level keyword RESP under keyword RELEASE).

The package- and problem-specific nature of these parameters makes it impossible to develop values for them *a priori*. Severity-related parameters may be defined for up to three population-density zones (second-level keyword NPOP under keyword SEVERITY). NPOP has three values: NPOP =1 indicates rural; NPOP =2 indicates suburban; and NPOP=3 indicates urban. The mean and range for each population-density zone (see Box 3-6) are taken from the demographic model in NUREG-0170 (NRC, 1977).

Box 3-6	**Population-Density Zones**
Rural (NPOP=1) Mean = 6 persons/km^2 (Range = 0 to 66 persons/km^2) **Suburban (NPOP=2) Mean = 719 persons/km^2 (Range = 67 to 1670 persons/km^2)** **Urban (NPOP=3) Mean = 3861 persons/km^2 (Range > 1670 persons/km^2)**	

Other parameters used in accident-risk calculation for which STANDARD values are available include atmospheric dispersion parameters and a number of individual parameters. They are discussed below.

3.13.2 Atmospheric Dispersion Parameters

STANDARD values are available for both atmospheric-dispersion options. The user may select one of two alternative analytical models with the Pasquill flag under the keyword PARM. If the Pasquill flag is set to 1, then six sets of tabular data (area, downwind distance, and time-integrated concentration) for Pasquill atmospheric-stability categories A through F are called up. The values in the tables are for a conservative instantaneous release---a small-diameter (10 m), ground-level "puff"---and are derived from Gaussian dispersion calculations in Turner (1969). These values are fixed and may not be changed, but there are no pre-assigned values for the probabilities of occurrence, which must be assigned by the user.

If the Pasquill flag is set to 2 (or any integer other than 1), then a table of user-definable areas and time-integrated concentrations is called up. National-average values are supplied as STANDARD values (Table 3-1). Like the six Pasquill category look-up tables, this option represents a conservative, idealized, small-diameter, ground-level dispersion pattern (no thermal buoyancy) and is also derived from Turner (1969). The innermost isopleth covers only about 460 m^2 (a little under 5000 ft^2) and has a maximum downwind extent of about 33 m (108 ft); the outermost isopleth covers 1.35 billion m^2 (about 521 sq. mi.) and has a maximum downwind extent of about 120 km (about 75 mi.). Since only one set of dispersion values is applied to the analysis in this option, probability of occurrence is not specified by the user.

3.13.3 Other Accident Parameters with STANDARD Values

Other accident-related parameters for which STANDARD values are available are listed in this section. Some of the values entered for these parameters are applied to all route segments in an analysis. Other parameters used in accident-risk calculations vary by route segment and can have no STANDARD value; they are discussed separately.

<u>BDF</u> This is the Building Dose Factor. This factor describes the entrainment of aerosol particles in ventilation systems (i.e., the fraction of particles of an external aerosol that remain in aerosol form after passing through a ventilation system). The BDF is used to modify inhalation doses to persons in urban structures. The STANDARD value of 0.05 represents a conservative average across a series of building types, including residential, office, and industrial structures (Engelmann, 1990). This value is about five times higher than the value for high-rise buildings with air-conditioning systems used by Finley et al., (1980) for New York City, which has been used in RADTRAN in the past.

<u>BRATE</u> This factor represents breathing rate and is used for calculation of inhalation doses. The breathing rate (BRATE = 3.30E-04 m^3/sec) of the Reference Man (70-kg adult male at light work)

derived from Shleien 1992; Table 12.6) has been used as the STANDARD value. The value in the cited table has been converted from liters per hour to m^3/sec.

<u>CULVL</u> This factor describes Clean-Up Level, which is the required level to which contaminated surfaces must be cleaned up. The STANDARD value is set equal to the proposed EPA guideline of 0.2 μCi/m^2 (EPA, 1977).
➡***Note that this value applies to the <u>sum</u> of deposited activity over all isotopes of a multi-isotope material.*** Although never officially adopted by the EPA or superseded by another standard, this value has become a *de facto* standard (Chanin and Murfin, 1996). Use of this value means that a relatively large amount of contaminated land would be interdicted, in theory, because decontamination to a level as low as 0.2 μCi/m^2 is virtually impossible. This is a controversial issue at present, and users who can justify use of more realistic values are urged to do so.

TABLE 3-1 STANDARD Isopleths and Time-Integrated Concentrations (Ci-sec/m^3/Ci

Isopleth Area (m^2)	Downwind Centerline Distance (m)	Time-Integrated Concentration
4.590E+02	3.345E+01	3.420E-03
1.530E+03	6.804E+01	1.720E-03
3.940E+03	1.051E+02	8.580E-04
1.250E+04	2.439E+02	3.420E-04
3.040E+04	3.694E+02	1.720E-04
6.850E+04	5.614E+02	8.580E-05
1.760E+05	1.018E+03	3.420E-05
4.450E+05	1.628E+03	1.720E-05
8.590E+05	2.308E+03	8.580E-06
2.550E+06	4.269E+03	3.420E-06
4.450E+06	5.468E+03	1.720E-06
1.030E+07	1.114E+04	8.580E-07
2.160E+07	1.310E+04	3.420E-07

5.520E+07	2.133E+04	1.720E-07
1.770E+08	4.050E+03	8.580E-08
4.890E+08	6.999E+04	5.420E-08
8.120E+08	8.986E+04	4.300E-08
1.350E+09	1.209E+05	3.420E-08

EVACUATION This parameter specifies evacuation time in days following a dispersal accident, where this includes time to respond to the accident and carry out a course of action. The STANDARD value is 24 h (1 day). Mills et al. (1995) analyzed 66 verified hazmat accidents in which evacuations were carried out and found that the mean evacuation time was approximately 1 hour. Even when response time is added, a 24-hour (1-day) value for this variable is conservative. [For non-dispersal accident evacuation, see TIMENDE.]

GECON This parameter specifies the Genetic Effects Conversion Factor. The STANDARD value is 1.0E-04 genetic effects/rem. This value is consistent with the recommendations of BEIR V (NRC/NAS, 1990) and ICRP 60 (ICRP, 1991). Estimates based on the only genetic effects (untoward pregnancy outcome and F_1 mortality) to have been documented in the atomic-bomb survivors have extremely high statistical and model uncertainties. Animal data, which is more reliable, consistently yield lower estimates. As noted in BEIR V, the recommended value is "probably …too high rather than too low" (NRC/NAS, 1990, p. 77).

INTERDICT This parameter specifies the threshold value for interdiction of contaminated land. The STANDARD value is 40, i.e., a value 40 times greater than CULVL, and it was taken from NUREG-0170 (NRC, 1977).

LCFCON This parameter specifies the Latent Cancer Fatality (LCF) Conversion Factors; units are LCFs per rem. The STANDARD values are 5.0E-04 LCF/rem for the general public and 4.0E-04 LCF/rem for workers. They have been adjusted for low-dose and low-dose-rate decrease in effects with a DDRRF (Dose and Dose Rate Reduction Factor) of 2. These values are consistent with the recommendations of BEIR V (NRC/NAS, 1990) and ICRP 60 (ICRP, 1991). The dose-response relationship is assumed to be linear with no threshold in order to agree with current regulations. However, the majority of available data indicate that the actual dose-response relationship at very low doses is likely to be considerably less and, as noted in BEIR V, is not incompatible with zero (NRC/NAS, 1990, p. 181). Thus, cancer risk estimates obtained from RADTRAN 5 will be generally conservative.

LOS The parameter is used to analyze loss-of-shielding accidents. It represents the fractional degradation of package shielding for each severity category in the analysis. Values may be any number between zero and 1.0.

NE This parameter is the neutron emission factor; it may be used to model neutron emissions following a loss-of-shielding accident. For commonly encountered isotopes that spontaneously emit neutrons (curium-242, curium-244, and californium-242), the NE values are already available in the isotope library. All other isotopes have no assigned NE factor. The NE keyword is applied only when the user wishes to assign a new value to an existing isotope or to a new material. The user must enter NE followed by the isotope name in standard format (or exactly as entered under keyword DEFINE) and the emission factor value in neutrons/s-Ci. The user must repeat the process (i.e., type NE followed by isotope name and NE factor value) for each isotope desired.

RADIST This parameter is used to specify an array of Radial Distances, which are used to define annular areas for dose-calculation purposes when the IACC Flag is set to 1.

RPCTHYROID This parameter is used to specify 1-year CEDE (rem per curie) to the thyroid from inhalation of radioisotopes of iodine for estimation of early-mortality risk. Radioiodine mainly travels to and irradiates a single organ, the thyroid. In previous releases of RADTRAN, however, the 50-year CEDE was used to approximate the 1-year dose. One-year committed doses to the thyroid have been calculated directly for RADTRAN 5. This new parameter was not included in the internal radioisotope database, since it would have meant adding a new column containing zeros for all isotopes but the radioiodines. The information has been included under the PRCTHYROID keyword instead. The STANDARD values are 1.27E+06 for iodine-131, 5.77E+06 for iodine-129, and 9.25E+05 for iodine-125.

SURVEY This parameter is used to specify the time (in days) required to survey contaminated land following a dispersal accident. The amount of deposited material removed by radioactive decay is calculated beginning with time of initial deposition. The longer a deposited material remains on the ground, the more is removed by decay and spread by forces such as wind and rain. The actual elapsed time between accident occurrence and completion of a survey is impossible to determine in advance, but is likely to be prolonged because of governmental and regulatory complexities. The STANDARD value is set to an unrealistically brief, but radiologically conservative, 10 days (NRC, 1977).

TIMENDE This parameter specifies the time, in days, required to effect evacuation following a non-dispersal accident. Three values are entered, one for each population-density zone (rural, suburban, and urban, in that order). TIMENDE represents the time required to move potentially exposed members of the public to safe distances beyond the areas specified by the RADIST keyword. The three STANDARD values are 0.67, 0.67, and 0.42 hours (Mills et al., 1995) [for dispersal accident evacuation, see EVACUATION]

UBF This parameter is the Urban Building Fraction; it describes either the fraction of the population that is indoors or the fraction of the area that is occupied by buildings, depending on the type of population model being used. The STANDARD value of 0.52 is for the latter model, and is taken from Finley et al. (1980). The value is most accurate for large cities such as New York and is somewhat conservative for smaller cities.

USWF This parameter is the Urban Sidewalk Fraction; it specifies the fraction of the population that is out of doors or the fraction of the population that occupies sidewalks, depending on the type of population model being used. The STANDARD pre-assigned value of 0.1 is for the latter model, and is taken from Finley et al. (1980). As with the UBF, this value is suitable for large cities and is conservative for smaller cities.

3.14 Role of the Input Echo

The first part of the output for any RADTRAN 5 run is the Input Echo, which is a simple no-frills repeat or "echo" of the input file (Figure 3-1). The echo shows the following:

- All STANDARD parameters with either the STANDARD values (user entered STANDARD after keyword INPUT) or with all values set to zero (user entered ZERO after keyword INPUT);
- User-defined values of parameters without STANDARD values;
- User-defined values of those parameters with STANDARD values which the analyst altered (following the keyword MODSTD); and
- All comment lines (lines beginning with &&).

The echo preserves all parameter values in an input file and, thus, is useful for quality-assurance purposes. ➡***The Input Echo is always part of the output file. Any RADTRAN 5 output lacking Input Echo pages should be considered potentially corrupt, incomplete and unsuitable for either publication or quality assurance.*** The remainder of the output is discussed in Chapter 4.

The example in Figures 4A-4D illustrates how an input file for a complex material (in this example, spent nuclear fuel) might be constructed. A single input file has been divided into four functional parts to illustrate the roles of the disparate types of data that must be entered. The data in Figures

4A-4D are based an actual input file, but are used here for illustrative purposes only. The top of Figure 4A shows comment lines and the TITLE, INPUT, FORM, DIMEN, and PARM initialization lines. Then, beginning in Figure 4A and continuing in 4B are input for the accident-severity categories. Release, aerosol, and respirable fractions are defined for each physical-chemical group. In this example, five distinct physical-chemical groups have been defined (COBALT, NOBLE, VOLATILE, CE_EU, and RUTHENIUM). The use of the DEFINE function also is illustrated in Figure 4B with a cobalt radioisotope. Figure 4C shows how MODSTD parameters are assigned when the user does not wish to accept the STANDARD values. Settings under the keywords FLAGS and PACKAGE are also illustrated in this figure. Fifteen isotopes and their properties are listed under the material SPENT FUEL, the only material in the package being analyzed. Finally, the package is assigned to a vehicle (TRUCK under keyword VEHICLE). Figure 4D shows how route-specific features (links, stops, and handlings) are described. This sample file shows several features of RADTRAN 5, such as:

- separation of isotopes in the material (listed under keyword PACKAGE) into more than one physical-chemical group (listed under keyword GROUP) and
- how data entered for route segments (keyword LINK), stops (keyword STOP), and handlings (keyword HANDLING) should appear.

FIGURE 4A RADTRAN 5 Input Echo-Initialization and Accident Severities

```
&& Edited Fri Feb 21 11:07:45 1997
&& This file has been altered
&& The data contained in this input file are for test purposes only.
TITLE  EXAMPLE FILE
INPUT  STANDARD
FORM  UNIT
DIMEN  6 10 18
PARM  1 3 4 0
SEVERITY
   NPOP=1
     NMODE=1
  6.03E-001  3.94E-001  3.00E-003  3.00E-006  5.00E-006  7.00E-
006
     NMODE=2
  6.23E-001  3.74E-001  3.00E-003  3.00E-006  5.00E-006  7.00E-
006
   NPOP=2
     NMODE=1
  6.02E-001  3.94E-001  4.00E-003  4.00E-006  3.00E-006  2.00E-
006
     NMODE=2
  6.22E-001  3.74E-001  4.00E-003  4.00E-006  3.00E-006  2.00E-
006
   NPOP=3
     NMODE=1
  6.04E-001  3.95E-001  3.80E-004  3.80E-007  2.50E-007  1.30E-
007
     NMODE=2
  6.24E-001  3.75E-001  3.80E-004  3.80E-007  2.50E-007  1.30E-
007
RELEASE
   GROUP=COBALT
      RFRAC
0.00E+000  0.00E+000  1.20E-002  1.20E-002  1.20E-002  1.20E-
002
      AERSOL
0.00E+000  0.00E+000  1.00E+000  1.00E+000  1.00E+000
1.00E+000
      RESP
       0.00E+000  0.00E+000  5.00E-002  5.00E-002  5.00E-002
5.00E-002
      DEPVEL   0.0100
   GROUP=NOBLE
      RFRAC
       0.00E+000  0.00E+000  0.00E+000  1.00E-002  1.00E-001
1.10E-001
      AERSOL
       0.00E+000  0.00E+000  0.00E+000  1.00E+000  1.00E+000
1.00E+000
      RESP
```

FIGURE 4B RADTRAN 5 Input Echo-Accident Severities (cont'd) and DEFINE

```
GROUP=VOLATILE
    RFRAC
     0.00E+000  0.00E+000  0.00E+000  1.00E-008  2.00E-004
2.80E-004
AERSOL
     0.00E+000  0.00E+000  0.00E+000  1.00E+000  1.00E+000
1.00E+000
    RESP
0.00E+000  0.00E+000  0.00E+000  5.00E-002  1.00E+000
1.00E+000
    DEPVEL   0.0100
  GROUP=CE_EU
RFRAC
     0.00E+000  0.00E+000  0.00E+000  1.00E-008  5.00E-008
5.00E-008
AERSOL
     0.00E+000  0.00E+000  0.00E+000  1.00E+000  1.00E+000
1.00E+000
    RESP
     0.00E+000  0.00E+000  0.00E+000  5.00E-002  1.00E+000
1.00E+000
    DEPVEL   0.0100
  GROUP=ACT_OTHERS
    RFRAC
     0.00E+000  0.00E+000  0.00E+000  1.00E-008  5.00E-008
5.00E-008
    AERSOL
     0.00E+000  0.00E+000  0.00E+000  1.00E+000  1.00E+000
1.00E+000
    RESP
     0.00E+000  0.00E+000  0.00E+000  5.00E-002  5.00E-002
5.00E-002
    DEPVEL   0.0100
GROUP=RUTHENIUM
    RFRAC
     0.00E+000  0.00E+000  0.00E+000  1.00E-008  1.00E-006
4.20E-005
    AERSOL
     0.00E+000  0.00E+000  0.00E+000  1.00E+000  1.00E+000
1.00E+000
    RESP
     0.00E+000  0.00E+000  0.00E+000  5.00E-002  5.00E-002
5.00E-002
    DEPVEL   0.0100

DEFINE CO60
     1.93E+003  2.50E+000  4.60E-001  7.60E-004  3.50E+005
2.50E+004
     2.00E+000  0.00E+000  0.00E+000
```

FIGURE 4C RADTRAN 5 Input Echo-MODSTD; Flags; Package; Vehicle

```
MODSTD
  UBF 6.000E-001
  USWF 5.000E-002
  MITDDIST 3.000E+001
  MITDVEL 2.400E+001
  DISTON FREEWAY   1.200E+001
  TIMENDE 1.000E+000 1.000E+000 2.500E-001
  CULVL 2.200E-002
  INTERDICT 4.000E+001
FLAGS
  REGCHECK 1
  IUOPT 2
  IACC 2
PACKAGE  SPENTFUEL 1.368E+001 1.000 0.000    5.20
      CO60      9.220E+001 COBALT
      KR85      6.100E+003 NOBLE
      SR90      5.960E+004 ACT_OTHERS
      RU106     1.620E+004 RUTHENIUM
      CS134     2.740E+004 VOLATILE
      CS137     8.760E+004 VOLATILE
      CE144     1.220E+004 CE_EU
      EU154     7.000E+003 CE_EU
      PU238     2.960E+003 ACT_OTHERS
      PU239     4.100E+002 ACT_OTHERS
      PU240     4.680E+002 ACT_OTHERS
      PU241     1.260E+005 ACT_OTHERS
      AM241     1.290E+003 ACT_OTHERS
      AM243     1.990E+001 ACT_OTHERS
      CM244     1.790E+003 ACT_OTHERS
      END
VEHICLE   1  TRUCK      1.368E+001 1.000 0.000    5.20    1.00
                   2.00   10.00 1.000     5.20
      SPENTFUEL     1.00
EOF
```

FIGURE 4D RADTRAN 5 Input Echo-Route-Specific Data

```
LINK  1 RURAL   TRUCK    2915.34  88.6  2.0    6.00  470.00 1.37E-007 R 1
LINK  2 RURAL  TRUCK   971.78  88.6  2.0    6.00  470.00 1.37E-007 R 2
LINK  3 SUBURB TRUCK  623.03  88.6  2.0  719.00  780.00 3.00E-006 S 1
LINK  4 SUBURB TRUCK  207.68  40.3  2.0  719.00  780.00 3.00E-006 S 2
LINK  5 SUBURB  TRUCK     69.22  44.3  2.0  719.00 1560.00 3.00E-006 S 1
LINK  6 SUBURB TRUCK    23.07  20.2  2.0  719.00 1560.00 3.00E-006 S 2
LINK  7 URBAN TRUCK    6.18  88.6  2.0 3861.00 2800.00 1.60E-005 U 1
LINK  8 URBAN TRUCK    0.33  24.1  2.0 3861.00 2800.00 1.60E-005 U 2
STOP STOP_TRUCK TRUCK   50.00  20.00   20.00 1.000  52.990
HANDLING LOAD       TRUCK      3.00    1.00   0.25
EOF
EOI
```

3.15 MASTER LIST OF RADTRAN 5 KEYWORDS

FIRST LEVEL	SECOND LEVEL	THIRD LEVEL	DESCRIPTION
TITLE	---	----	User-defined alphanumeric title; preferably descriptive
INPUT	STANDARD or ZERO	----	User elects whether to use standard input values or not
DIMEN	---	----	Enter three (3) values: NSEV, NRADIAL, NISOPLETH
PARM	---	----	Sets four (4) flags
FORM	UNIT or NONUNIT	----	User selects output format: dose (UNIT) or health effects (NONUNIT)
INGFILE	---	----	For ingestion dose; Enter COMIDA output filename if other than default
LOS	---	----	Enter shielding degradation fraction for each severity category
SEVERITY	NPOP	NMODE	Enter probabilities for NSEV severity categories for NPOP =1, 2, and 3 and for each Mode
RELEASE	GROUP	RFRAC	Release fraction for Group p
	---	AERSOL	Aerosol fraction for Group p
	---	RESP	Respirable fraction for Group p
	---	DEPVEL	Deposition velocity. for Group p
	CLINE	----	Centerline downwind distance (m)
	AREADA	----	Isopleth area (m^2) for n areas
	DFLEV	----	Time-integrated concentrations for n areas (Ci-sec/m^2)
	PSPROB	----	Pasquill probabilities (6 values)
	ISOPLETHP	----	Populations of NISOPLETH isopleths; see DIMEN)
DEFINE	---	----	Isotope name followed by 10 values
NONRAD	HIGHWAY GENERAL DEDICATED	NPOP NPOP NPOP	Highway fatality rates (km^{-1}) General rail fatality (km^{-1}) Dedicated rail fatality rates (km^{-1})
TRANSFER	GAMMA NEUTRON	----	Coefficients for gamma radiation Coefficients for neutron radiation
PACKAGE	[END]	-----	Enter 5-variable array for each package type followed by isotope contents followed by END
VEHICLE	----	----	Enter 11-variable array for each vehicle type followed by the package(s) on the vehicle
MODSTD	SMALLPKG	----	Size of smallest package for nondispersal analysis
	TIMENDE	----	Evacuation time (3-number array), non-dispersal
	UBF	----	Urban Building Fraction
	USWF	----	Urban Sidewalk Fraction
	EVACUATION	----	Evacuation time (days)
	SURVEY	----	Survey interval (days)
	INTERDICT	----	Interdiction threshold
	DISTOFF	FREEWAY	Enter 3-variable array
	---	SECONDARY	Enter 3-variable array
	---	STREET	Enter 3-variable array
	---	RAIL	Enter 3-variable array
	---	WATER	Enter 3-variable array
	DISTON	FREEWAY	Minimum perpendicular distance to vehicle traveling opposite direction (m)
	---	SECONDARY	Minimum perpendicular distance to vehicle traveling opposite direction (m)
	---	STREET	Minimum perpendicular distance
	---	RAIL	Minimum perpendicular distance (m)
	---	WATER	Minimum perpendicular distance to vehicle Traveling opposite direction (m)
	MITDDIST	----	Distance for Maximum In-Transit Dose (m)
	MITDVEL	----	Speed for Maximum In-Transit Dose (m/s)

	CAMPAIGN	----	Campaign duration (years)
	DDRWEF	----	Distance-dependent rail worker exposure factor (inspections/km)
	RADIST	NPOP	Enter NRADIAL distances (see DIMEN) for loss-of-shielding exposure in NPOP = 1, 2, and 3
	BDF	----	Building Dose Factor
	CULVL	----	Clean-up Level (uCi/m^2)
	BRATE	----	Breathing Rate (m^3/s)
	FMINCL	----	Minimum no. of rail classifications and/or inspections
	RPD	----	Ratio of Pedestrian Density
	RR	----	Rural shielding factor
	RS	----	Suburban shielding factor
	RU	----	Urban shielding factor
	FNOATT	----	Number of flight attendants
	NE	----	(isotope name) neutron emission factor (neutrons/sec/Ci)
	RPCTHYROID	----	1-yr dose to thyroid via inhalation (rem per curie)
	LCFCON	----	Latent cancer fatalities conversion factors (2-number array)
	GECON	----	Genetic effects conversion factor
FLAGS	ITRAIN	---	1=General freight; 2=Dedicated Rail
	IUOPT	----	Shielding Options
	IACC	----	1=nondispersal; 2=dispersal
	REGCHECK	----	1=regulatory checks performed 2=regulatory checks not performed
EOF			"End of File" special keyword
LINK	---	----	Enter 11-variable array for each link (route segment)
STOP	---	----	Enter 7-variable array for each stop
HANDLING	---	----	Enter 5-variable array for each handling
EOF			"End of File" special keyword
EOI			"End of Input" special keyword; terminates input

.

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4 RADTRAN 5 OUTPUT

The RADTRAN 5 output consists of several types of results and tables. Output may be requested in short or long formats. The short or summary format is the first type. It consists of the Input Echo and summary tables of output. Full-length output consists of the Input Echo, all of the input data in tabular form, and detailed tables of output values as well as the summary tables.

4.1 Input Echo and Input Data Tables

The Input Echo was described in Chapter 3, Section 3.8. Most of the input data also are presented in tabular form in the full-length output. The tables make locating a particular variable's value simpler than counting the variable's position in an array, which is necessary if only the Input Echo is available.

4.2 Consequences of Incident-Free Transportation

After the input data summary tables, actual RADTRAN 5 calculational output begins with the heading "INCIDENT-FREE SUMMARY." The first table of output is titled "In-Transit Population Exposure in Person-Rem" (Box 4-1). Doses to passengers, crew, members of the public residing near the link (off-link) and sharing the link (on-link) for each route segment (link) are given in this table, as are subtotals for rural, suburban, and urban segments, and totals according to segment type and exposure group.

Box 4-1

```
INCIDENT-FREE SUMMARY
                    ******** **** *******
          IN-TRANSIT POPULATION EXPOSURE IN PERSON-REM

            PASSENGER    CREW   OFF LINK   ON LINK   TOTALS
RURAL1    0.00E+00      6.84E+01  4.02E-01  1.82E+01
8.69E+01
RURAL2    0.00E+00      2.28E+01  1.60E-01  1.50E+01
3.79E+01
SUBURB1  0.00E+00    1.46E+01  8.96E+00  6.44E+00
3.00E+01
SUBURB2  0.00E+00    1.07E+01  8.02E+00  2.62E+01
4.49E+01
SUBURB3  0.00E+00    3.25E+00  1.99E+00  5.94E+00
1.12E+01
SUBURB4  0.00E+00    2.37E+00  1.78E+00  2.39E+01
2.80E+01
URBAN1    0.00E+00      1.45E-01  9.87E-03  2.29E-01     3.84E-
01
URBAN2    0.00E+00      2.85E-02  9.52E-02  4.27E-01     5.50E-
01
URBAN3    0.00E+00      3.24E-02  2.20E-03  2.13E-01     2.47E-
01
URBAN4    0.00E+00      6.87E-03  2.30E-02  4.32E-01     4.62E-
```

Doses incurred at stops and during handling are tabulated separately. The stop example shown in Box 4-2 is for a shipment of PWR spent fuel. The words "POINT-SOURCE DOSE" indicate that a point-source model was used to perform the calculation. The point-source model is selected when the user

Box 4-2 SAMPLE OUTPUT TABLE FOR STOP DOSE: 1 STOP BY TRUCK

STOP EXPOSURE IN PERSON-REM

POINT-SOURCE DOSE	STOP_TRUCK	9.6E-01

TOTAL   9.6E-01

places receptors at radial distances from the shipment greater than 2 CPDs (characteristic package dimensions). Box 4-3 shows a similar calculation for handling (e.g. loading of a spent fuel cask onto a truck by a crane). A line-source model is used in the latter case because of the handlers' proximity to the cask.

Box 4-3 SAMPLE OUTPUT TABLE FOR HANDLING DOSE: LOADING

HANDLING EXPOSURE IN PERSON-REM

	HANDLING	VEHICLE	MATERIAL
DOSE	LOAD	TRUCK	SPENTFUEL
2.33E-01			

➡**Incident-free doses are *consequences.*** If the transportation event being analyzed actually takes place, then these types of doses will be incurred. In RADTRAN 5, the probability term is set to 1.0, although it is actually equal to 1.0 minus the very small probability of an accident. The user may request that dose output be multiplied by what are often called "stochastic risk factors" to estimate potential health effects (NONUNIT after keyword FORM). The resultant estimates of potential health effects are *risk estimates*, because a "stochastic risk factor" is itself a probability term. It means that, for a large population receiving a given collective dose, there will be, on the average, some number of excess health effects observed as a result of the exposure. The results of accident dose-risk calculations, which are discussed in the next section, are true risks. That is, each dose consequence term has been multiplied by a probability of occurrence. Dose risks can also be converted into health risks; doing so entails an additional multiplication by an additional probability (the risk factor).
➡**Health-effects risk estimates are secondary or derivative values and should never be reported alone without the associated dose-risk values.**

4.3 Importance Analysis

An importance analysis is performed for incident-free doses on a link-by-link basis. The importance analysis describes the change in the output resulting from a 1-% change in an input variable. All input variables that affect the incident-free dose calculation are listed in descending order from the largest positive change to the largest negative change. The actual value of the change in the output and the percentage change are listed in the output table (Box 4-4). ➡This analysis will not yield accurate results if the package has a large neutron component because the method used to determined dose versus distance for neutron radiation is not amenable to the partial-derivative approach used to generate the importance analysis. However, for all applications where packages are modeled as emitting 100% gamma radiation, the importance analysis is reliable.

4.4 Population Risks and Consequences from Accidents

The primary accident-related output of RADTRAN 5 depends on whether UNIT or NONUNIT was entered under keyword FORM (see Chapter 3). If UNIT was selected, then the output consists of tables of dose risks and doses (primary consequences). A sample consequence calculation for spent fuel shipment by truck is shown in Box 4-5. The results are broken down by accident severity (rows) and by route segment (columns). When large numbers of route segments are analyzed in a single run, this part of the output can be many pages

Box 4-4 Example of Importance Analysis Output for a Single Link

```
INCIDENT-FREE IMPORTANCE ANALYSIS SUMMARY
 ESTIMATES THE PERSON-REM INFLUENCE OF A ONE PERCENT
INCREASE IN THE PARAMETER

   LINK       PARAMETER                    IMPORTANCE      CHANGE
SEG1----------------------------------------------------------------
          DOSE RATE FOR VEHICLE (TI)        8.693E-01    10.0000 %
          NUMBER OF SHIPMENTS               8.693E-01    10.0000 %
          DISTANCE TRAVELED                 8.693E-01    10.0000 %
        NUMBER OF CREW MEMBERS              6.837E-01     7.8657 %
        K ZERO FOR CREW DOSE                6.837E-01     7.8657 %
     CREW DOSE ADJUSTMENT FACTOR            6.837E-01     7.8657 %
         K ZERO FOR VEHICLE                 1.855E-01     2.1343 %
      NUMBER OF PEOPLE PER VEHICLE          1.815E-01     2.0881 %
                TRAFFIC COUNT               1.815E-01     2.0881 %
          SHIELDING FACTOR (RR,RS,RU)       4.020E-03     0.0462 %
           POPULATION DENSITY               4.020E-03     0.0462 %
      NUMBER OF FLIGHT ATTENDANTS           0.000E+00     0.0000 %
     RATIO OF PEDESTRIAN DENSITY (RPD)0.000E+00     0.0000 %
    DIST DEP RAIL WORKR EXPOSR FACTR 0.000E+00     0.0000 %
                   VELOCITY                -1.051E+00   -12.0881 %
   DISTANCE FROM SOURCE TO CREW            -1.367E+00   -15.7314 %
```

long. Because ingestion doses are societal (i.e., affect the general population rather than only the population under the plume footprint), they are calculated and tabulated separately (Box 4-6). Population dose-risks for all pathways except ingestion are given in the output table shown in Box 4-7 for the same sample file. Dose-risks are given for each route segment, broken down by exposure pathway. Non-ingestion consequence and risk results are summed by population-density category to give summations for the total rural, suburban, and urban links traversed by the shipments under analysis. Ingestion dose-risks can only be incurred if a dispersion accident takes place in an agricultural (rural) area and if no interdiction or other preventive measures are taken. ➨***For convenience, ingestion doses are assigned to rural route segments, although persons everywhere are potentially affected (Box 4-8)***. This should not be forgotten when the user is assessing dose-risks for the other areas. Ideally, the ingestion dose-risk should be distributed among all population groups on the basis of population weighting or other apportionment methods.

BOX 4-5 ACCIDENT CONSEQUENCES TABLE IN OUTPUT - EXAMPLE

RADIOLOGICAL CONSEQUENCES
50-YEAR POPULATION DOSE IN PERSON-REM

CATEGORY	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6
1	000E+00	000E+00	000E+00	000E+00	000E+00	000E+00
2	000E+00	000E+00	000E+00	000E+00	000E+00	000E+00
3	2.53E+00	2.53E+00	3.03E+02	3.03E+02	4.97E+02	4.97E+02
4	2.53E+00	2.53E+00	3.03E+02	3.03E+02	4.97E+02	4.97E+02
5	2.69E+01	2.69E+01	3.23E+03	3.23E+03	5.29+03	5.29E+03
6	3.57E+01	3.57E+01	4.28E+03	4.28E+03	7.02E+03	7.02E+03

BOX 4-6 INGESTION CONSEQUENCES TABLE IN OUTPUT (CALCULATED FOR RURAL LINKS ONLY)

RADIOLOGICAL CONSEQUENCES IN PERSON-REM
50 YEAR SOCIETAL INGESTION DOSE - EFFECTIVE

LINK	SEVER: 1	SEVER: 2	SEVER: 3	SEVER: 4	SEVER: 5	SEVER: 6
SEG1	0.00E+00	0.00E+00	1.72E+00	1.75E+00	3.01E+02	4.07E+02
SEG2	0.00E+00	0.00E+00	1.72E+00	1.75E+00	3.01E+02	4.07E+02

BOX 4-7 EXPECTED VALUES OF POPULATION RISK IN PERSON-REM
(By link, for groundshine, inhalation, resuspension, and cloudshine exposure pathways; ingestion calculated separately)

LINK	GROUND	INHALED	RESUSPD	CLOUDSH	TOTAL
SEG1	2.14E-03	2.61E-06	1.01E-05	1.75E-07	2.16E-03
SEG2	7.15E-04	8.71E-07	3.35E-06	5.83E-08	7.19E-04
SEG3	1.55E+00	1.71E-03	6.55E-03	1.29E-04	1.56E+00
SEG4	5.16E-01	5.69E-04	2.18E-03	4.29E-05	5.19E-01
SEG5	1.27E-02	1.39E-05	5.32E-05	1.06E-06	1.28E-02
SEG6	6.79E-04	7.41E-07	2.84E-06	5.65E-08	6.83E-04
RURAL	2.86E-03	3.48E-06	1.34E-05	2.33E-07	2.88E-03
SUBURB	2.30E+00	2.53E-03	9.70E-03	1.91E-04	2.31E+00
URBAN	1.49E-02	1.63E-05	6.24E-05	1.24E-06	1.50E-02
TOTALS:	2.31E+00	2.55E-03	9.78E-03	1.92E-04	2.33E+00

BOX 4-8 SOCIETAL DOSE RISK FOR INGESTION (PERSON-REM)

LINK	GONADS	EFFECTIVE
SEG1	2.82E-03	2.57E-03
SEG2	9.40E-04	8.57E-04
TOTAL	3.76E-03	3.43E-03

SOCIETAL INGESTION RISK BY ORGAN - PERSON-REM

LINK	BREAST	LUNGS	RED MARROW	BONE SURF.	THYROID	REMAINDER
SEG1	1.62E-03	1.53E-03	1.80E-03	1.55E-03	1.48E-03	3.78E-03
SEG2	5.39E-04	5.10E-04	6.01E-04	5.17E-04	4.93E-04	1.26E-03
TOTAL	2.16E-03	2.04E-03	2.40E-03	2.07E-03	1.97E-03	5.04E-03

If NONUNIT was selected under keyword FORM, then the output consists of tables of projected health-effects (secondary consequences). An example is shown in Box 4-9.

Box 4-9 HEALTH EFFECTS OUTPUT - EXAMPLE

EXPECTED VALUES OF POPULATION RISK IN LATENT CANCER FATALITIES

	GROUND	INHALED	RESUSPD	CLOUDSH	TOTAL
Link 1	1.06E-06	1.09E-09	4.21E-09	8.86E-11	1.07E-06
Link 2	3.53E-07	3.63E-10	1.40E-09	2.95E-11	3.55E-07
Link 3	7.66E-04	6.93E-07	2.66E-06	6.52E-08	7.69E-04
Link 4	2.55E-04	2.31E-07	8.87E-07	2.17E-08	2.56E-04
Link 5	8.51E-05	7.70E-08	2.96E-07	7.24E-09	8.54E-05
Link 6	2.83E-05	2.57E-08	9.85E-08	2.41E-09	2.85E-05
Link 7	1.29E-05	1.15E-08	4.42E-08	1.10E-09	1.29E-05
Link 8	6.78E-07	6.06E-10	2.33E-09	5.79E-11	6.81E-07
Link 9	1.43E-06	1.28E-09	4.91E-09	1.22E-10	1.44E-06
Link 10	7.54E-08	6.73E-11	2.58E-10	6.43E-12	7.57E-08
RURAL	1.41E-06	1.45E-09	5.61E-09	1.18E-10	1.42E-06
SUBURB	1.13E-03	1.03E-06	3.94E-06	9.66E-08	1.14E-03
URBAN	1.51E-05	1.35E-08	5.17E-08	1.29E-09	1.51E-05
TOTALS:	1.15E-03	1.04E-06	4.00E-06	9.80E-08	1.16E-03

4.5 Interdiction Table

A table indicating how many, if any, isopleth areas would be interdicted for each accident-severity category also is included in the output. Interdiction is based on ground deposition levels. When an area is interdicted, persons in the affected area will already have received an inhalation dose and an external radiation (cloudshine) dose from passage of the plume, and be exposed to external radiation from ground-deposited particulates (groundshine) for the time that elapses prior to evacuation. The values in the interdiction table depend on user-supplied information on interdiction action levels and parameters describing atmospheric dispersion (if any) in each accident-severity category. See Section 4.5.2 for a sample dose calculation. An example of an interdiction table is shown in Box 4-10.

Box 4-10 INTERDICTION AREAS TABLE - EXAMPLE

AREAS WITH TOTAL CONTAMINATION RATIO GREATER THAN 40.000
(THE AREAS MARKED WITH AN 'X' ARE INTERDICTED AND HAVE
NO 50 YEAR GROUNDSHINE DOSE AND NO INGESTION DOSE.)

AREA/SEVERITY	1	2	3	4	5	6
1	-	-	X	X	X	X
2	-	-	X	X	X	X
3	-	-	X	X	X	X
4	-	-	-	-	X	X
5	-	-	-	-	X	X
6	-	-	-	-	X	X

4.6 Early Fatality Calculations

Two other types of impacts are calculated regardless of whether UNIT or NONUNIT output was selected. They are:

- risk of early fatality (also known as nonstochastic or prompt effects) from radiation exposure, and
- risk of early fatality from nonradiological causes (i.e., from ordinary traffic accidents).

4.6.1 Radiological Early Fatality Risk

The example shown in Box 4-11 is an actual result from a sample file. Results are calculated for each route segment (identified by user-defined labels) under LINK column. The total is also calculated. In this example, **no** member of the public would receive a prompt dose exceeding the early-fatality threshold in any severity of accident. The example is typical of most analyses. Among the few instances in which non-zero fatality risks would be predicted in this category are loss-of-shielding accidents for medical gamma sources such as cobalt-60 or cesium-137.

Box 4-11 EARLY FATALITY OUTPUT

LINK		EARLY FATALITIES
SEG1		0.00E+00
SEG2		0.00E+00
SEG 3		0.00E+00
	TOTAL	0.00E+00

4.6.2 Nonradiological Fatality Risk

The results for nonradiological fatality-risk output formerly were broken down on the basis of “normal” and “accident,” where “normal” refers to health risk from vehicle emissions, and “accident” refers to death from physical trauma following an accident. The emergence of considerable data regarding threshold values for the various chemical constituents of vehicle exhaust has made linear extrapolation untenable, and the “normal” factor is now omitted. Effects in the Normal Occupational category were always extremely small, and their omission will have no effect on the result at the recommended two-digit level of reporting. Results for accident-related fatalities are broken down into occupational (OCC) and non-occupational (NON-OCC) categories. There are two reasons for this:
The probability of an effect and the population of radioactive shipment crewmembers are both very small.
The sub-populations most at risk (e.g., persons with severe respiratory problems) are usually not employed in the transportation sector.
The Accident Non-Occupational category reflects the chance of a member of the public being killed in a transportation accident in each of the various roadway-type categories. The Accident Occupational category values indicate expected driver/crew deaths from physical trauma. Standard values for both categories are obtained from national and state statistics, but the user may substitute other values available to him or her. ➡Non-radiological risks are usually several orders of magnitude larger than other risks computed by RADTRAN

4.7 Individual Dose Calculations

4.7.1 Maximum Individual In-Transit Dose (incident-free)

The maximum individual in-transit dose for incident-free transportation calculates a dose to an individual located at a specified distance from a transport link (highway, railroad, and waterway) during the passage of one or more shipments at a specified speed. The user may define the distance and speed values. ➡In previous releases of RADTRAN, distance and speed were fixed at 30 m and 15 mph, respectively; but are now definable by the user.

4.7.2 Maximum Individual Downwind Doses (following a dispersion accident)

Maximum individual downwind doses are calculated at the mean downwind centerline distance for each isopleth. The doses are the sums of individual doses from the three so-called “prompt” exposure pathways --- cloudshine, inhalation, and the first several hours of groundshine (exact number of hours determined by user-supplied value of the EVACUATION parameter). The output resembles the example in Box 4-12, where the downwind distance is given under the column heading CNTRLINE. Individual doses are given for each accident severity category in the analysis. The example gives a single row, but the actual output would contain as many rows as there were isopleths. The values may be used, for example, to determine whether Federal exposure guidelines might be exceeded and, if so, at what distances from an accident site.

Box 4-12 Maximum Individual Dose Output: Example
[only first row shown]

```
MAXIMUM INDIVIDUAL CONSEQUENCE (DOSE IN REM)
FROM INHALATION, CLOUDSHINE, AND GROUNDSHINE EXPOSURE
DURING EVACUATION

CNTR LINE    SEVER: 1  SEVER: 2  SEVER: 3  SEVER: 4  SEVER: 5
SEVER: 6
  3.34E+01     0.00E+00   0.00E+00   3.05E-02    3.20E-02    1.87E+00
2.76E+00
```

4.8 Population Data in Output

RADTRAN 5 performs three calculations that provide the user with quantitative information about potentially exposed populations. They are listed and discussed in this section.

4.8.1 Population within User-Specified Distance of Route

Incident-free dose to the public is integrated over a user-specified perpendicular distance (in meters) from the shipment centerline. This distance is designated by keyword DISTOFF (STANDARD value for DISTOFF = 800m). Population density values are generally derived from census data either directly or by means of a routing code. RADTRAN 5 calculates the total population within the DISTOFF distance along each route segment from distance and population-density input. For multi-year shipment campaigns, however, a simple algebraic calculation will underestimate the total potentially exposed population because no account would be taken of the residence times of various fractions of the population. Therefore, RADTRAN 5 includes a model that uses 1990 census statistics to correct for the movement of persons into and out of a contaminated area (Smith et al, 1996).

4.8.2 Population Potentially Exposed to Radiation from Dispersed Particulates

4.8.2.1 Uniform Population Density

The total population within a user-specified dispersion isopleth pattern is calculated and written to a table in the output file. Unless the user specifies otherwise, this calculation proceeds on the basis of two simplifying assumptions:

- the distribution of population under the footprint of the dispersion cloud is uniform
- the population density within the bandwidth that is used in incident-free calculations is assigned to the
  entire area under the plume footprint.

Because of the simplifying assumption of uniform population density, wind direction has no effect on the results. Thus, wind direction is **not** a RADTRAN input variable. Furthermore, wind direction, even if known for all locations, would not greatly affect the results of a risk analysis over a long route (Mills and Neuhauser, 1999b). For very short routes, use of the simplifying assumptions could yield results different from, although not necessarily less than, actual values.

4.8.2.2 Non-Uniform Densities Defined with ISOPLETHP

➨In a new feature, users can examine potential doses calculated with a nonuniform population distribution under the plume footprint. RADTRAN 5 contains a separate, optional subroutine that allows the user to assign distinct population densities to each isopleth (second-level keyword ISOPLETHP under RELEASE). The resulting dose-risks are tabulated and printed in the output. There are no STANDARD values for this calculation, and the first alternative (uniform population distribution) is used if ISOPLETHP is not entered. ISOPLETHP is intended to be a supplementary tool to assist the analyst in assessing potential accident consequences at specific locations. For example, wind-direction related differences in downwind population densities might be examined with this tool. However, the lack of wind rose data for most locations on most routes limit this application to special cases.

4.9 Population Changes over Time

➨A **new feature** in RADTRAN 5 allows the user to account for population in-migration and out-migration over time. The feature is intended for use in the analysis of multi-shipment campaigns that take place over more than one year. The user enters the duration of the campaign in years under keyword CAMPAIGN. By means of an algorithm based on Census Bureau demographic data, the total number of persons residing within the specified bandwidth around the transportation route(s) under analysis is calculated for the specified period of time (Smith and Neuhauser, 1995).

5 ANALYSIS METHODS

Analysis procedures and strategies are considered in this chapter, with emphasis on understanding the roles of the important input parameters and minimizing the amount of problem-specific data that must be entered. Where appropriate, differences from previous releases of RADTRAN are also discussed.

5.1 PACKAGE and SHIPMENT Values

5.1.1 Package and Conveyance Dimensions

Some package-related terminology, which might otherwise become confusing, requires clarification. The term “package dose rate” is **not** fully synonymous with the term “Transport Index” (TI). All RAM packages have a dose rate, but not all RAM packages have a TI. TI is a regulatory quantity that applies only to certain package types, as defined in regulations of the International Atomic Energy Agency, the U.S. Department of Transportation and the U.S. Nuclear Regulatory Commission (NRC) (49 CFR 173 and 10 CFR 71, respectively). In 10 CFR 71 and elsewhere, TI is defined as the **maximum** radiation level in millirem per hour at any point 1 meter from the external surface of a package. For exclusive-use shipments, however, the regulations abandon the TI concept. Instead, they regulate the dose rate at 2 m from the “vertical planes projected by the outer lateral surfaces” of the railcar or vehicle. ➡***Values for dose rate 1 m from the surfaces of package(s) and conveyance(s) must be entered in RADTRAN 5 regardless of which regulations govern the package(s) being analyzed.***

RADTRAN is designed to take advantage of the fact that this dose rate at 1 meter from the package surface is a **maximum** and either (1) is directly measured for regulatory compliance purposes or (2) can be calculated from a similar maximum measured at 2 meters. Real 3-dimensional packages, however, often have dose rates that are considerably **less** than the maximum at many other points on the package or conveyance surface (Figure 5-1A). For example, dose rates at 1 m from the surface of a DHLW (Defense High Level Waste) rail cask may vary by three orders of magnitude from 32.9 mrem/hr at cask midpoint to 0.02 mrem/hr at the corner (Wan & Scheringer, 1983). Spreads of one order of magnitude for gamma readings and two orders of magnitude for neutron readings were recorded at the cask surface on a TN-24 spent-fuel-storage cask with aged fuel contents (EPRI, 1987).

RADTRAN 5 does not account for the dose-rate variation described above. No generalized method of predicting field shape from package shape now exists, even for isotropically radiating materials, and few package contents are isotropically radiating. Many package contents display complex field-strength variations (e.g., spent fuel). In the absence of a general method, the approach taken in RADTRAN is necessarily geometrically simple and conservative. The package is modeled as an isotropically radiating sphere that emits the ***effective dose rate*** at a radius equal to {[(0.5)CPD] + 1}, where CPD is the ***Characteristic Package Dimension*** (Figure 5-1B). ➡***The CPD is an actual package dimension.*** For example, in cylindrical packages (e.g., most spent fuel casks), the characteristic package

Figure 5-1A Example of Realistic Radiation Field Strength Isobar [-----] Around a Cylindrical Package with a CPD Equal to Length and a Maximum Dose Rate at 1 meter as indicated. (Not to Scale)

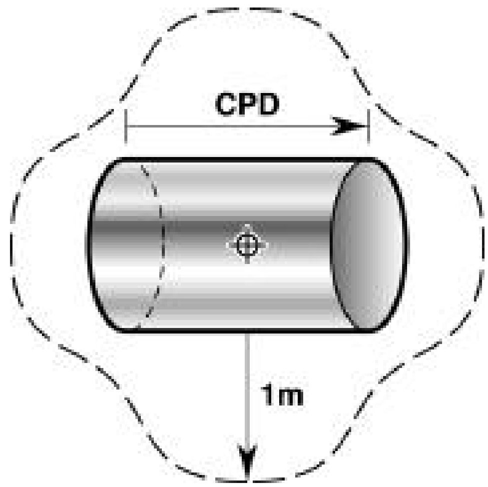
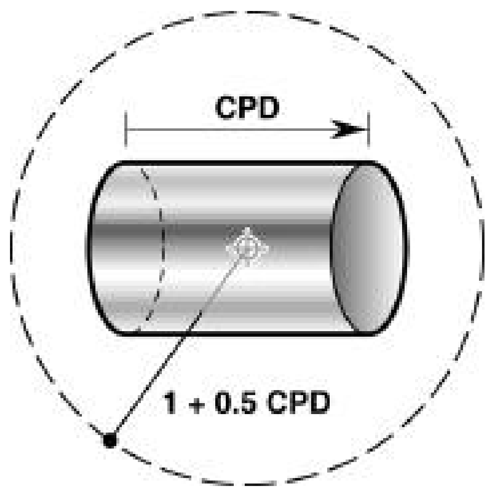


Figure 5-1B Radiation Field is converted in RADTRAN 5 into a spherical, isotropically radiating field with its centerpoint at the geometric center of the package. The Field Strength at the radial distance of 0.5CPD + 1 is equal to the Maximum Dose Rate at 1 meter. (Not to Scale)



dimension is equal to length.[4] For a sphere, it is the diameter, and for a cubical package it is the longest internal diagonal.
The RAM-carrying vehicle is also assigned a characteristic dimension. The user enters values for characteristic dimensions (in meters) for each package and vehicle type. The code calculates a coefficient, K_o, from the CPD. K_o is often called the 'shape factor,' and it is used in subsequent dose calculations.[5] ➨***RADTRAN incident-free results are highly sensitive to the value of K_o, and the user should select values of dose rate and CPD with great care.***

[4] For analysis of a package or vehicle with a characteristic dimension greater than 4 m, the basic formula for calculating K_o significantly overestimates the actual dose rate, and RADTRAN 5 automatically makes an adjustment. For a package dimension greater than 4 m, the value for the actual characteristic package or vehicle dimension is replaced with a value for an effective package dimension, which is calculated by RADTRAN 5 according to the following equation:

$$D_{eff} = 2 \quad (1 + 0.5\ D_{act})^{3/4} - 0.55$$

where D_{eff} = effective dimension and D_{act} = actual dimension.

[5] For close-proximity exposure groups, a line-source model is used (Weiner & Neuhauser, 1992).

The third type of CPD is “crew-view” CPD. It is the characteristic dimension of a package silhouette as viewed from the crew’s vantage point. It is often markedly different from the silhouette of the same package for other exposure groups (e.g., handlers). For cubical packages the “crew-view” is the diagonal across one side; for spherical packages, it is the diameter, just as for the regular CPD (Figure 5-2). The application of the crew-view CPD is discussed in Section 5.1.3.

As noted above, the entire shipment also is assigned a characteristic vehicle dimension (CVD). For example, the trailer of a tractor-trailer carrying a packed array of radiopharmaceutical packages may be treated as a single entity for the purpose of calculating external radiation doses. Finley et al, (1988) contains an example of this application.

Figure 5-2A
The Characteristic Package Dimension (CPD) of a Cylinder Is Length (meters) [ ]
Crew-View CPD is Diameter (meters)
[ ]

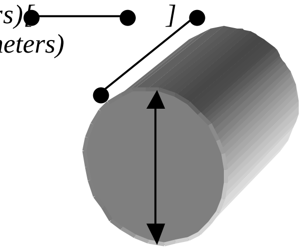


Figure 5-2B
CPD of a Cube is Longest Internal Diagonal (meters)
Crew-View CPD is Diagonal on a Side (meters)

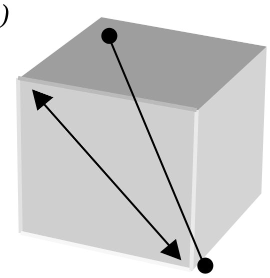
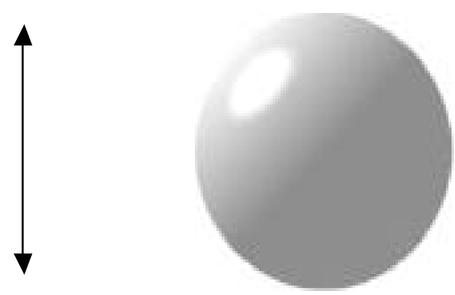


Figure 5-2C
CPD and Crew-View CPD of a Sphere are both equal to the diameter (meters)



5.1.2 Package and Shipment Dose Rates

Dose-rate values are among the most important data entered in a RADTRAN 5 input file. Recall that the maximum dose rate in mrem/hr at any point 1 m from a package or at 2 m from the vertical planes projected by the outer lateral surfaces of the transportation vehicle is regulated by law. Recall also that the maximum dose rate at 1 m is a RADTRAN 5 input value, which is used to estimate conservatively the field strength around the package or shipment.

The field-strength estimate for each ***package*** is used to calculate handler dose. The field-strength estimate around a vehicle (***shipment***) is used to calculate doses to persons beside the transport link (off-link), doses to persons sharing the transport link (on-link), and doses to persons at stops. The following guidance indicates the best ways of handling various package/shipment configurations.

Single-package shipments.
This is the simplest case. The shipment dose rate may be set equal to package dose rate, which normally is conservative. However, if the package is significantly narrower or shorter than the conveyance in which it is transported, then the actual shipment-level dose rate should be calculated or measured and used instead. The source-to-crew distance is usually the distance from the ***center*** of the package to the crew compartment. However, if a distinct crew-view dimension is used, then the same dose rate is used but the source-to-crew distance is measured from the ***end*** of the package closest to the crew compartment.

Multiple-package shipments.

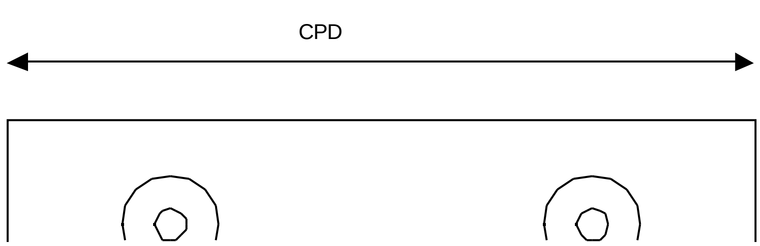
· **Arrays**. This configuration usually applies to small packages. In most cases, numerous packages fill the space available for cargo or palletized groups of packages are evenly distributed within the space. The shipment dimension (CVD) represents the conveyance cargo space (usually trailer or railcar length). One should note that the estimate of dose rate at any given distance from a shipment increases non-linearly with increasing shipment dimension for a fixed shipment dose rate (DR_v).
➨***Use of a shipment dimension greater than approximately 10 m is not recommended.***

One still enters individual package dose rates as well as a shipment-level dose rate for the conveyance.
➨***The shipment dose rate is not equal to the sum of the package dose rates.*** It must be measured directly or calculated by hand because self-shielding usually makes the shipment dose rate significantly smaller than the sum of the individual package dose rates. An example of this approach may be found in Finley et al. (1988). Individual package dose rates also are required, however, because doses to handlers are always calculated on the package level.

· **Two or a few packages**. These are often special cases involving Type B packages. Individual cobalt-60 pins for commercial irradiators, for example, might be shipped in the following configuration: one per package; two packages at a time; truck mode. The vehicle-level dimension selected by the user to represent such a shipment depends on package placement within the cargo space. Type B and other heavy packages are generally evenly spaced to distribute the load. For example, in the case of two packages shipped in a single trailer, they could be tied down at the centerpoints of the two halves (measured from front to back) of the trailer bed. Total trailer length could be the CVD for this configuration; the maximum dose rate 1 meter from the trailer edge midpoint would have to be measured or calculated DR_v (Figure 5-3, Option 1). Alternatively, one could model the same example as two shipments each with a CVD equal to half the trailer length and with shipment dose rates measured at 1 m from the midpoint of each trailer half (see Option 2). For a 7x3-m trailer and packages 1-m in diameter, Option 1, with the larger vehicle dimension, yields a dose result that is about 40% higher than for Option 2. This occurs because of the non-linear nature of the k_0 and DR_v functions. As was noted above, this non-linearity tends to increasingly overestimate the dose-rate values as CVD increases. Therefore, Option 1 may be preferred for analyses where conservatism is desired, but Option 2 gives a better dose estimate.

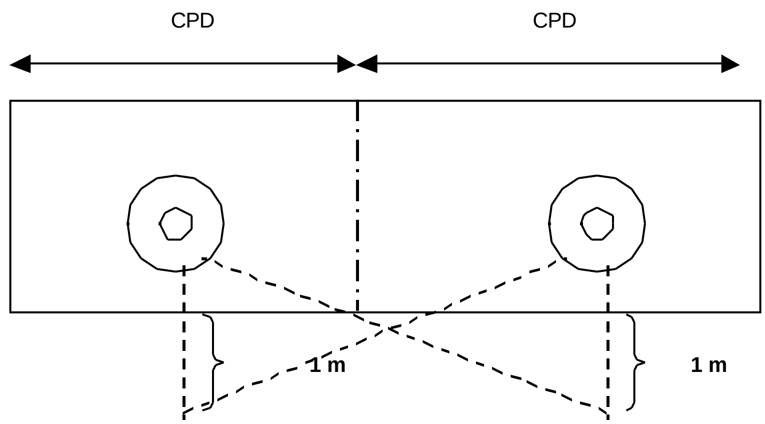
· **Other configurations.** There are many possible arrangements of packages within a vehicle, and RADTRAN permits all variations to be characterized. Among special cases one might encounter are those in which the edge of the trailer or railcar is coincident with the edge of the package (e.g., TRUPACT shipments to the Waste Isolation Pilot Plant). If it is a single package, then the vehicle and package dose rates are equal. When a package occupies most or all of the cargo space available (e.g., many spent-fuel casks), then the package CPD is set equal to the CVD.

Figure 5-3A Option 1 - *Models Two or a Few Packages Widely Separated in the Same Conveyance - Model as Single Shipment with CPD Equal to Trailer or Railcar Length and Dose Rate Calculated at 1 m from midpoint of trailer or railcar.*



1 m

Figure 5-3B Option 2 – *Models Two or a Few Packages Widely Separated in the Same Conveyance – Model as Two or More Separate Shipments each with CPD Equal to a Fraction of Trailer or Railcar Length and Dose Rate at 1 m from Midpoint of each Fraction of Trailer or Railcar.*



5.1.3 Crew Shielding

➨**Crew shielding may be directly accounted for in RADTRAN 5 by means of the crew modification factor.** In previous releases of RADTRAN, crew shielding could only be accounted for indirectly, by artificially increasing the source-to-crew distance. With the crew modification factor, the user can easily account for shielding that may be installed in cabs of semi-tractors or ship's bulkheads, for example. Data that must be supplied by the user are:

- The "crew-view" dimension. Conveyances such as combination trucks often have "crew-view" dimensions that are smaller than those used to calculate doses for members of the public.
- The crew-to-source distance, which should be measured from the **closest edge** of the package or packed array to the center of the closest location for a crewmember (usually the crew cabin).

5.2 Gamma and Neutron Components of Dose Rate

Values for a neutron component of dose rate for fission neutrons are available for use in RADTRAN 5. The derivation of these values was originally given in the RADTRAN 4 Technical Manual (Neuhauser and Kanipe, 1989). To summarize briefly, they were obtained with neutron cross-section data from the ENDF/B-V (Magurno, 1983) cross-section data library generated with the NJOY code (MacFarlane, 1982). The source was assigned an energy spectrum obtained from Oak Ridge National Laboratory calculations of the neutron flux at the surface of a lead-shielded spent fuel shipping cask. The neutron transport calculations were performed with the ONEDANT code, which solves the one-dimensional, multigroup, Boltzmann transport equation by the discrete ordinates method (O'Dell, 1982). The ENDF library, NJOY system, and ONEDANT code are discussed and evaluated for use in transportation analysis by Parks et al. (1988).

To be compatible with the RADTRAN calculational strategy, the neutron rate as a function of distance is expressed in the following form

$DR(x) = K\, e^{-\mu x} (1 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4)/x^2$,

where

$DR(x)$	=	the dose rate as a function of x
x	=	distance in meters from the source
K	=	constant, and
μ	=	linear absorption coefficient for the surrounding medium (air).

The linear absorption coefficient for air (μ_{air}) was assigned a value of 7.42E-03 m^{-1} (Madsen et al., 1986; p. 43). Four unitless coefficients (a_1, a_2, a_3, and a_4) were then derived for fitting the shape of the dose rate-vs.-distance curve to the shape of the selected neutron transport curve in air at 50 percent relative humidity. These values are:

a_1 = 2.02E-02
a_2 = 6.17E-05
a_3 = 3.17E-08
a_4 = 0.0.

Although it is unlikely that another neutron transport curve might be appropriate, the user is allowed to enter new values for the coefficients into the input data file with keyword TRANSFER (see Chapter 3 for discussion of data entry). All four coefficients must be entered even if only one changes in value. Workstation/mainframe users enter them as the last four numbers in the five-number array under the second-level keyword NEUTRON and the first-level keyword TRANSFER (Table 3-2). The first number in this array is the linear absorption coefficient (μ), which also may be redefined by the user.

A similar treatment is possible for gamma radiation (second-level keyword GAMMA under TRANSFER), but the atmospheric effect (i.e., attenuation and buildup in air) is comparatively insignificant. Therefore, for gamma radiation the values of μ, a_1, a_2, a_3, and a_4 are set to zero in order to reduce the exponential term in the dose rate equation to unity. The equation for gamma thus reduces to the form used for a gamma point or line source in the RADTRAN calculational strategy, namely, $DR = K/x^2$ or $DR = K \times /x$ (Madsen et al., 1986, p. 13).

Separation of dose rate into neutron and gamma components is useful only for packages in which a significant fraction of the external dose rate is attributable to neutrons (e.g., aged spent fuel). A breakdown of the gamma and neutron components of dose rate at 1 meter for representative truck and rail casks and fuel ages of from 5 to 25 years is given in Parks, Hermann & Knight (1985). For most materials, the user should treat the external radiation field as consisting solely of gamma radiation. The user always has the option of performing external transport calculations and curve fitting to obtain new coefficients. An analysis of a multiple-package shipment containing dissimilar packages should *not* rely on extrapolation from package-by-package gamma-neutron breakdown, because of differential shielding and absorption by surrounding packages. The calculated or measured *shipment-level dose rate* may be split into gamma and neutron components, if necessary, that are derived from measurement or modeling of the shipment configuration.

5.3 Multiple-Radionuclide Materials

5.3.1 Assignment of Physical-Chemical Groups

Few radioactive materials consist of single radionuclides; most are mixtures. The physical and chemical properties of radionuclides and their compounds vary widely, and the behavior of radionuclides and their compounds in response to mechanical and thermal forces potentially encountered during accidents depends strongly on these properties. The first step toward accounting for them is to list all of the important radionuclides in the package(s) being analyzed under the PACKAGE keyword. ➡**The importance of an accurate radionuclide inventory cannot be underestimated.** When analyzing numerous small packages with variable contents, however, one may use statistical methods. Allow the code to automatically enter radionuclide-specific data directly from the internal isotope library whenever possible. Data entry is thereby simplified, and by reducing the amount of hand-entered data, the frequency of input errors is reduced. Complex materials containing up to 200 radionuclides can be modeled realistically. Methods are available, however, to reduce the number of nuclides considered without loss of accuracy, and these are discussed in Section 5.2.2.

The second step is to determine whether physically and chemically distinct groups of elements are represented in the material(s) being considered. Examples of chemically distinct groups are noble gases (e.g., krypton), volatiles (e.g., cesium in various forms), and transuranic oxides (e.g., plutonium oxide). An element may fall into more than one group in a material. An example of an isotope that may be in two distinct groups is cobalt-60 in pressurized water reactor (PWR) spent fuel. The isotope is an activation product and is found (1) in metallic fittings of fuel assemblies and (2) in crud on the surface of the fuel rods. The former is in a non-dispersable form that does not contribute to potential releases in severe accidents, but the latter may be spalled off of the fuel rods following impact. The resulting particulates may then be available for release. Since cobalt-60 produces a high-energy gamma, it is very important to model this element correctly. Only the cobalt-60 in crud should be modeled as available for release in analyses of PWR spent fuel.

For a given material, only elements with similar release behavior in **all** accident-severity categories should be grouped together. For example, ruthenium and cesium are volatile elements which will behave similarly in many thermal environments, but ruthenium may undergo chemical changes in a severe fire and an oxidizing environment that cesium does not. Therefore, these two chemical species should be assigned to two separate physical-chemical groups.

The designed-in flexibility of RADTRAN 5 allows each group to be treated separately. Since as many as 15 physically and chemically distinct groups of elements may be used in a single analysis, even the most complex materials can be modeled. An example of a complex material (spent fuel) is given in the sample input file in Chapter 3.

Each physical-chemical group must be assigned appropriate values for the release fractions (RFRAC), aerosol fractions (AERSOL), respirable aerosol fractions (RESP), and deposition velocity (DEPVEL). ➨***The Dispersability Categories used in earlier releases of RADTRAN are no longer used in RADTRAN 5***. However, the table of former default values for these categories remains a good guide to AERSOL and RESP values in the absence of any better information, and it is reproduced here from Neuhauser & Kanipe (1992).

Table 5-1. General Guide to AERSOL and RESP Values Suitable for All Severity Categories

Material Type	***Aerosol Fraction***	***Respirable Fraction***
Immobilized	1E-06	0.05
Loose Chunks	1E-02	0.05
Large Powder	1.5E-01	0.05
Small Powder or Nonvolatile Liquid	1E-01	0.05
Flammable	1E+00	1
Liquid	1E+00	1
Gas	1E+00	1
Undispersed (Loss-of-Shielding)	0	0

In summary, each radioactive element or compound is assigned to a group according to its physical and chemical properties. An element also may be assigned to more than one group if it appears in more than one physical-chemical form in the material being analyzed.

For shipments carrying packages with more than one type of contents, each package type must be separately characterized. The behavior of a multiple-package array in potential accident conditions is often different from the behavior of a single package, even if the packages are all identical. In an impact accident, for example, packages on the struck side of the vehicle generally will absorb more impact force than packages on the opposite side. Certain accident scenarios may involve what is referred to as inertial crush; when the force is translated from one package to the next in a manner such that package(s) distant from the impact point may be most affected. Packages also may act as thermal barriers in a fire accident, shielding other packages beyond them. Factors such as these must be considered and evaluated on a shipment-specific basis before assigning release fractions, etc.

5.3.2 Use of a Relative Hazard Index to Reduce Large Radionuclide Inventories

If the number of radionuclides in a material is large, as in spent fuel, for example, then radionuclides that contribute less than a predetermined percentage to the overall hazard (e.g., 10, 1.0, or 0.1 percent) may be disregarded to simplify the analysis. The use of a relative hazard index for RAM transportation analyses was pioneered by Sandia National Laboratories. Various types of indices are discussed below.

5.3.2.1 Effective Dose Equivalent Factors

These factors give dose per unit intake for inhalation and ingestion for each radionuclide and are compiled and updated regularly by the DOE and the EPA (e.g., DOE, 1988a,b and EPA, 1993). When each is multiplied by the package inventory of the appropriate radionuclide, the resulting list represents the relative hazard of the material. For example, the data in DOE (1988b) was used to select those isotopes that contribute to 99.9% of the total health hazard in a recent DOE EIS dealing with research reactor spent fuel (DOE, 1995).

5.3.2.2 Maximum Permissible Concentrations (MPCs) and similar metrics

Atmospheric dispersion generally represents the primary, and often the only, means of dispersing radionuclides beyond the immediate vicinity of an accident site, even in extremely severe accidents and even for waterway modes. For this reason, values such as the International Commission on Radiological Protection (ICRP) Maximum Permissible Concentrations in Air (MPCs), Annual Limits on Intake (ALIs), and Derived Air Concentrations (DACs) are attractive candidates for use in developing a relative hazard index. All three are described in ICRP (1979) and ICRP (1990). For example, Maximum Permissible Concentrations in Air (MPC_{air}) were used to develop a radiological hazard (RADHAZ) index for radionuclides present in 10-year-old PWR spent-fuel during analysis of repository alternatives (Wilmot et al., 1983). The authors used the following relationships:

$$\frac{\text{Inventory of isotope i (Ci)}}{MPC_{air} \text{ for isotope i}} = RADHAZ_i$$

and

$$\sum RADHAZ_i \text{ over all isotopes in spent fuel} = \text{Total Radiological Hazard (for inhalation pathway).}$$

By retaining only those radionuclides that contribute, by summation on a rank-order basis, to 99.9% of the total radiological hazard (inhalation), Wilmot et al. reduced the size of the radionuclide list entered into RADTRAN to less than 10 without noticeably affecting the result. The radionuclides that were retained were cobalt-60, strontium-90, ruthenium-106, europium-155, cesium-134 and cesium-137, and several isotopes of plutonium.

5.3.2.3 Activity Limits

A similar method, based on Activity Limits (particularly A_2 values) can be used. The International Atomic Energy Agency (IAEA) defines A_2 as "the maximum activity of radioactive material, other than special form radioactive material, permitted in a Type A package" (IAEA, Safety Series 6, 1985). A Type A package meets the General Requirements for All Packagings and Packages, but is not accident-resistant, as are Type B packages.

This approach yields a nuclide list similar to that obtained with MPCs for the spent-fuel example above. With 5-year-old spent fuel, additional elements such as americium and curium are included in the list. None of these methods should be applied blindly, however. Krypton-85, for example, is generally included in the final isotope list for spent fuel (e.g., Wilmot et al., 1983; DOE, 1995). Although krypton-85 is inert and poses a relatively low hazard, it is present in spent fuel as a gas and much of the inventory would be released in the event of a severe accident, rather than remain trapped in the fuel and cask structures as many solids would. Thus, it is reasonable to include this radionuclide regardless of its hazard index. Similarly, radionuclides that are present in large amounts by mass, even thought their specific activities are low (e.g., uranium in spent fuel), or that are highly biologically active (e.g., tritium and iodine-131) should not be automatically excluded on the basis of a numerical hazard ranking alone.

In summary, the user may apply a relative hazard index to a multiple-nuclide material in order to simplify an analysis. However, special features such as gaseous state, mass fraction, and biological activity, should be considered when compiling a defensible final list.

5.3.2.4 Historical Methods

Two methods that were used to simplify computations when computers were less powerful and access to them more limited should be mentioned, although they are seldom, if ever, used today. The first was a weighted-average method, used to approximate the gamma source strength of spent fuel in

NUREG-0170 for loss-of shielding accidents (NRC, 1977, Tables A-5 and A-6). Today, it is recommended that measured surface-dose-rate values be used.

Also in NUREG-0170, the entire inventory of volatile fission products in spent fuel was modeled as cesium-137, the single most hazardous radionuclide in this class (NRC, 1977, Table A-5). This historical method yields results that are too high. The practice is obsolete since it is now easy to realistically model the actual radionuclide inventories of spent fuels and most other complex materials.

5.4 Route Data

This section deals with analyses in which the routes being analyzed are defined by a set of route segments. Additional RADTRAN applications of route segments are discussed in Section 5.5.3.

5.4.1 Aggregate Route Segments and Other Data

An aggregate route segment is defined as the sum of all portions of a route that satisfy some predefined criterion. For purposes of analysis, it is treated as a single route segment. The resulting collective or aggregate route segment has all properties specified by the criterion except length. The length of the aggregate segment is equal to the sum of the portions as defined above.

➨ ***Route-segment aggregates, however defined, must be jointly inclusive and mutually exclusive.*** In other words, (a) the sum of the lengths of all the various route-segment aggregates must equal the total length of the route and (b) no individual segment of the route can be a member of more than one aggregation class defined by the criteria.

The most common aggregation criterion is population density. This criterion was used in NUREG-0170 (NRC, 1977), and has been used in numerous risk analyses since (e.g., Wilmot et al., 1983; DOE, 1995). Aggregated population-density data are readily obtained from the output of transportation routing codes such as HIGHWAY (Johnson et al., 1993) for truck mode and INTERLINE 5.0 (Johnson et al., 1992) for rail mode. Both of these codes, developed at Oak Ridge National Laboratory (ORNL), yield aggregate data for each node-to-node interval along the route. That is, all the rural segments between two major intersections are summed, as are the suburban and urban segments, respectively.

Stops may also be treated in an aggregate manner, especially when several similar stops may occur in the course of a single shipment. Madsen & Wilmot, 1983, provide this information for long-distance truck shipments. Similar data for rail operations in the Unites States was collated by Ostmeyer, 1986, from information found in Wooden, 1986. This is discussed at greater length in Section 5.3.4.

5.4.2 Linear Route-Specific Analysis

This section consists primarily of suggestions and useful information to assist the user in describing and analyzing route-related data. To perform linear route-specific analyses, a route is usually broken into
(a) links or segments, each of which represents a portion of the actual route,
(b) stops, each of which represents a stop along the route, and
(c) handlings, each of which represents a loading, unloading, or intermodal transfer event that occurs during the trip(s) being analyzed.

Up to 60 distinct route segments, 7 stops, and 8 handlings may be analyzed in a single computer run. If the number of route segments, stops, or handlings exceeds the maximum number per run for RADTRAN, then the user must perform multiple runs. The results of multiple runs may be collated in spreadsheets such as Microsoft Excelä to yield total risk and consequence values for a complex problem.

5.4.3 Summation Check

➨***As noted above, the sum of the segment lengths should equal the total route length.*** Because there can be no internal check to ensure that this condition is satisfied, the user ***must*** perform this check. This check is most easily performed when data are entered in a spreadsheet, which is another reason why the use of spreadsheets is recommended for keeping tracking of the large amounts of data required by RADTRAN 5. The use of spreadsheets in building input files is discussed in Neuhauser et al. (1995)

5.4.4 Population Density

High-resolution sources of population data are available. The Bureau of the Census is the single best source of digitized data for the United States. Census data must be converted into population-density values suitable for use in RADTRAN. The population density within a predetermined bandwidth (usually 1600-m) of the highway or railroad must be determined for overland modes. Population densities under a plume footprint must also be determined if the user is applying the ISOPLETHP option. Methods for developing these population data with a GIS (Graphical Information System) have been developed at SNL (Mills, Neuhauser, & Kanipe, 1995). ORNL also has updated its previous routing codes (HIGHWAY and INTERLINE) with a GIS platform. The new code, called TRAGIS, will be publicly available in late 2000 (Johnson et al., 2000).

5.5 Accident Rate

The units for this variable are usually accidents per vehicle-kilometer. National accident-rate data are compiled and published annually by various groups in the U.S. Department of Transportation (USDOT) such as the National Transportation Safety Board (NTSB) and the Federal Rail Administration (FRA). Some of these data are available in electronic format (e.g., DOT, 1994). The relationship between accidents and railroad track class is discussed in McClure et al. (1988). The U.S. Coast Guard collects U.S. maritime accident data. Lloyd's of London maintains the Lloyd's Maritime Information Service accident reports, which are available for a fee.
Less comprehensive but locally more detailed data can sometimes be obtained from state and municipality highway or transportation departments (e.g., Smith, 1982).

In most cases, data collected in the United States are reported either in terms of accidents per one million vehicle-miles or in tabular form with two columns of data (total number of accidents and total millions of vehicle-miles traveled). The latter are often embedded in tables with various other data and must be extracted by the user. The data are not broken down into convenient rural, suburban, and urban categories. For example, the category labeled as URBAN by the USDOT usually is designated according to political boundaries (i.e., city limits) rather than actual population densities. Accident rates must be converted to metric units. Methods for developing rural, suburban, and urban rates are discussed in NRC (1977) and Wilmot (1983).

When analyzing carriage by a specific type of vehicle, an accident rate for that vehicle type should be used whenever available, rather than less vehicle-specific values. For example, nearly all Highway Route Controlled Quantity (HRCQ) shipments of radioactive materials by highway mode are carried by combination trucks (tractor-trailers), and USDOT data are available for this truck type. The latter should be used in preference, for example, to data from the All Vehicles category. The data source and category should always be stated in the documentation of an analysis.

Most data sources, whether they explicitly state so or not, include only reportable accidents (i.e., those that exceed some dollar value in damages or those that involved a fatality). Correcting for underreporting only serves to raise the fraction of accidents of low severity (and hence to lower the fraction of high-severity accidents) and so is usually neglected. Accident-rate data for more than one year may be averaged, if desired, and the use of multiple years of data is recommended.

➡The accident-rate parameter is sometimes written less than rigorously as accidents/kilometer, but this should ***never*** be interpreted to mean an accident count per kilometer of roadway or railroad. The number of accidents that have occurred in a given route segment, if left unadjusted for usage of that route segment, is an improper (and useless) value. The denominator should always be taken as referring to vehicle-kilometers unless explicitly stated otherwise.

For air and maritime modes, accidents *per voyage* or accidents *per air transit* are often the forms in which data are presented. They can be converted to accidents/vehicle-kilometer if nautical-mile or air-mile distance values, or average trip distances, or some similar parameter can also be obtained. If they are used without modification, comment lines should be added to any analysis that uses an alternative form of accident-rate data to make sure improper comparisons are not made with other risks calculated on a per vehicle-kilometer basis.

5.6 Vehicle Density and Vehicle Occupancy

The DOT sources cited above also supply data on vehicle density for highway mode travel. For most analyses performed at Sandia, average vehicle occupancy is conservatively set to 2, although it is usually closer to 1 (e.g., DOT, 1994).

5.7 Segment Character Designation

Although segment-specific population densities must be entered, the user is asked, in addition, to indicate whether each segment is rural, suburban, or urban in *character.* The user enters R, S, or U to indicate rural, suburban, or urban character, respectively. Character designation controls the selection of accident-severity fractions, controls whether an ingestion-dose calculation is performed, and determines the selection of building-shielding factors [RR, RS, and RU (see Keyword Master List, Chapter 3)].

If the segment character designation is R, then the ingestion pathway is included, but if a segment is designated as S or U, ingestion is not calculated. However, the ingestion code (COMIDA) also gives a calculation for a so-called "maximum man," who is essentially a subsistence farmer (Abbott and Rood, 1994a,b). This dose value is always included in the RADTRAN output. It will bound any doses potentially incurred by a suburban resident with a backyard tomato plot, for example, in the unlikely event that the individual continues to grow and eat tomatoes subsequent to a contamination event.

In addition, if a segment is designated U, then expected values of total inhalation dose are modified to account for its two main components:

1. dose for persons indoors, and
2. dose for persons out of doors.

To obtain the first value, the baseline total inhalation dose is calculated on the basis of a uniform population density; then that dose is multiplied by the product of Urban Building Fraction (UBF) and Building Dose Factor (BDF). The UBF accounts for the fraction of persons indoors (or the amount of land surface occupied by buildings rather than streets, sidewalks, parking lots, parks, etc.), and the BDF accounts for the partial removal of particulates by building ventilation systems (Finley et al., 1980). The UBF has a STANDARD value of 0.9; the BDF has a STANDARD value of 0.05 (Englemann, 1990). The BDF factor used in RADTRAN 4 (8.6E-03; from Finley, 1980) is now considered too small. Both the UBF and BDF may be altered, of course.

The second term, which accounts for inhalation dose to persons outside of buildings (e.g., pedestrians, shoppers, and commuters), is calculated separately. In this term, the base dose value is multiplied by the product of Urban Sidewalk Fraction (USWF) and Ratio of Pedestrian Density to residential population density (RPD). The STANDARD values for USWF and RPD are 0.1 and 6.0, respectively (Finley et al., 1980). The RPD allows the user to account for non-residents, and all of them are modeled as being out of doors. The sum of the two terms is the adjusted collective inhalation dose.

5.8 Link Type

Link type is used to distinguish between various roadway types for highway modes only (truck, commercial van, and passenger van). If the user sets the link type to 1, then the route segment is modeled as a limited-access divided highway (i.e., an Interstate highway or other highway built to similar engineering standards). If the link type is set to 2, then the combination of zone designation and link type determines how the roadway is modeled. If the link type is set to 2 and the zone is designated either R or S, then the roadway is modeled as a non-limited-access, non-divided highway (e.g., an U.S. highway). If the link type is set to 2 and the segment is designated as U in character, then the roadway in that segment is modeled as a city street. For all other modes, the link type is set to 3.

This scheme is diagrammed as follows.
Link Type 1 ⇨ Limited-Access Divided Highway; Any Population Density
Link Type 2 ⇨ Zone R or S ↣ U.S. Highway (non-limited-access, non-divided)
Zone U ↣ City Street
Link Type 3 ⇨ Any Non-Highway Mode

This flexibility is important even for highway-route controlled quantity (HRCQ) shipments such as spent fuel, which are required by DOT routing regulations to use Interstate highways. Access routes to and from the Interstates and state-designated alternate routes, which often must be evaluated in environmental documents, can be analyzed readily by use of the link-type settings. Differences in accident rates, population densities, traffic densities and other factors that may change according to road type, must be accounted for if the analysis is to be meaningful. In a recent example, an Interstate route from Florida to Washington State was compared with a route that avoided urban areas by traveling on U.S. Highways (Mills & Neuhauser, 1998).

5.9 Fraction of Land under Cultivation

The user may enter values from 0.0 to 1.0 for this parameter only if the link is identified as R (rural in character; see Link Type above). If a link is identified as S or U (suburban or urban), then the RADDOG input file generator code automatically enters a zero for this parameter. If the user is manually creating an input file, then he or she must enter a zero value for all non-rural segments. The variable is used in the ingestion-dose calculation and accounts for the fraction of area in agricultural production, as opposed to the area occupied by roads, driveways, dwellings, barns, commercial buildings, parking lots, parks, forests, etc. No account is taken of seasonal differences. There is no STANDARD value for this parameter. Maximum values for this parameter are available from publications of the U.S. Bureau of the Census, but only for counties, a relatively low level of resolution.

If one wishes to “force” calculation of an ingestion dose for a link that is actually suburban or urban in character, then the user can designate the link as rural and enter a value for the fraction of land under cultivation. The latter value should be at least a factor of 4 or 5 smaller than the rural value. For example, the *County and City Data Book* (USBC, 1988) lists St Louis County, Missouri, which includes the City of St. Louis, as having 42,000 acres in cropland. The total area of the county is 506 square miles and the average population density was 1962 persons per square mile in 1988. At that time the fraction of land under cultivation in this highly urban county was approximately 0.13 (13%). Nearby Atchison County, Missouri, on the other hand, which is predominately rural (population density was 14.6 persons per square mile) had a fraction of land under cultivation of 0.77 (77%) in the same year. That is over five times the value for St. Louis County.

5.10 Population under Plume

Accidents may occur that result in airborne dispersion of RAM package contents. These accidents are characterized with the user entries for accident rate, severity fraction, release fraction, aerosol fraction, respirable fraction, and meteorological conditions. As in previous releases of RADTRAN, the area under the dispersion plume, the so-called plume "footprint" can be modeled as having the same population density as the bandwidth around the transportation corridor. This is normally acceptable for probabilistic analysis purposes. The population density in this bandwidth (usually 1600 m wide) is the basis for designation as rural, suburban or urban; off-link populations for incident-free dose calculations are located within the bandwidth. However, this modeling assumption leads to excessively large overestimates of downwind population for urban route segments. It is possible, but less likely, that a plume originating in a rural or suburban route segment would encounter higher density areas shortly beyond the bandwidth boundary. In order to better characterize such specific situations, an individual population density for each downwind isopleth may now be entered under the ISOPLETHP keyword. The Bureau of the Census is the best source of digitized information on population distribution in the United States. The population data must be used in conjunction with a GIS system to obtain useful plume footprint values.

5.11 Non-Linear Applications

In the so-called non-linear applications of RADTRAN 5, the links do **not** represent a sequential or aggregated set of route segments that define a route. This freedom to define route segments in nontraditional ways that has been built into RADTRAN 5 is extremely useful. The user can analyze and compare the same route or route segment(s) in a variety of conditions. Examples of applications include:

- comparisons of daytime and nighttime population densities (e.g., Mills and Neuhauser, 1999a);
- comparisons of rush-hour and non-rush-hour traffic conditions;
- comparisons of current and projected population densities (e.g., Neuhauser and Weiner, 1992a)
- doses in enclosed spaces such as airplanes from leaking radioactive material package(s) (Neuhauser, 1992).

This powerful analytical tool is limited in usefulness only by the quality and quantity of data available to the user.

5.12 Stop Data

To review from Chapter 3, for each stop (or an aggregate of similar stops), the user assigns values to the following stop parameters:

- alphanumeric identifier, up to 10 characters;
    - vehicle identifier (previously defined under keyword VEHICLE);
    - population density (persons/km^2) **OR** number of persons (#);
    - minimum radius of annular area (m);
    - maximum radius of annular area (m);
    - shield fraction;
    - stop time (hr).

There are two alternative methods for estimating the size of the potentially exposed population. In the first method, the minimum and maximum radii are set equal to each other; this is interpreted by the code to mean that dose will be calculated at an *average radial distance* from the shipment. In this option, the third value in the array is interpreted to mean *number of persons present at the stop.* These persons are modeled as if they were located at the specified average radial distance from the shipment(s) for the duration of the stop. In the second method, the maximum and minimum radii are not equal. This is interpreted by the code to mean that it should compute the area of an annulus (with the vehicle at its center) that has an inner radius equal to the smaller of the two radius values and an outer radius equal to the larger of the two values. The third value in the array is then taken to be a *population density,* which is used to calculate the number of persons within the annulus (the product of the population density and the calculated annular area).

➨***The user must be careful not to get the two stop options confused***. For example, entering a population-density value, rather than a count, along with an average distance (i.e., making the two radial distances equal), would mean the density would be interpreted as a specific number of persons located at that average distance. The result would usually be considerably in error. Studies that provide information on the values of these parameters for highway mode include Madsen & Wilmot (1983) and Griego et al. (1996).

If more than one stop is expected (e.g., cross-country truck shipment) and if exact stop locations cannot be known in advance, then the total expected stop time may be allocated to a single "aggregate" stop with average parameter values. For materials shipped by common carrier, this is often the only workable method. For truck shipments the aggregated stop time has been conservatively estimated to be equal to 0.011 hours per kilometer of travel (Madsen & Wilmot, 1983). This value includes rest stops, meal stops, and overnight stops on long trips. The use of aggregate stops for highway mode is common because one can expect truck stop locations to be restricted or pre-designated only when one is analyzing heavily controlled or monitored shipments. Most train stops are in railyards, and several reports have examined the potential for rail worker dose (Wooden, 1986; Ostmeyer, 1986; and ORNL, 1990). In the case of carriage by vessel, port-call stops are usually known well in advance and may last 24 hours or longer (Neuhauser & Weiner, 1992b).

5.13 Use of Stop Model for LOS Analyses with Robust or Special-Form Materials

The LOS model in RADTRAN 5 is suitable for use with many RAM shipments such as radiopharmaceuticals, which are typically shipped in small amounts in non-accident-resistant Type A packages. For shipments of these materials, moderate to severe accidents can be expected to result in complete loss of contents of all affected packages. The LOS model in RADTRAN 5 is intended for such situations. The contents are presumed to be lying on the ground or on some vehicle surface in a manner that permits little self-shielding. Thus, the entire radionuclide inventory is multiplied by a gamma photon energy or neutron emission factor, as appropriate, to calculate a source strength. However, this approach is inappropriate for special-form materials and other robust materials such as spent fuel that can be expected largely to retain their structural integrity even in extremely severe accidents. In the latter case, the annular-area option of the stop model should be used to estimate LOS doses. The source strength should be estimated from the product of the surface dose rate of the material and whatever shielding factor is appropriate to account for only partial degradation of the packaging. The latter calculation will require a separate run of the code.

5.14 Handling Data

To review the discussion in Chapter 3, for each handling, the user assigns values to the following parameters following the keyword HANDLING:

- alphanumeric identifier, up to 10 characters;
- vehicle identifier (previously defined under keyword VEHICLE);
- number of handlers;
- average source-to-handler distance (m);
- handling time per package (hr/package).

The values of the last three parameters listed are a function of package size. Large containerized packages that are handled by spreader crane require several handlers. To move such a package from a truck to a ship's hold, for example, requires a crane operator, a spotter, and four or more additional workers (Neuhauser & Weiner, 1992b; Weiner & Neuhauser, 1992a). The package is modeled as a line source or a point source depending on distance. The average source-to-handler distance may be only a few meters, in which case a line source model is used. For packages that are smaller than a spent fuel cask but still large enough to require movement by forklift or similar equipment, the average source-to-handler distance decreases but so does the number of handlers. Finally, small packages that can be picked up and moved by hand (e.g., many radiopharmaceuticals) are analyzed in RADTRAN 5 by use of an empirical factor that relates handling time per package, source-to-handler distance, and other factors (keyword SMALLPKG; see Section 3.6).

5.15 Use of HANDLING or STOPS to Model Inspector Dose

Highly regulated shipments (e.g., spent fuel) are often subjected to redundant radiological and mechanical inspections by various government entities, carrier representatives, shippers of record, etc. Each inspection adds an increment of inspector dose. Inspectors generally must be close to the package/conveyance being inspected; their exposure may be modeled by use of the HANDLING or STOPS subroutine. Suggested parameter values are discussed in Ostmeyer (1986) for rail mode and Weiner & Neuhauser (1992a,b) for ship and highway modes.

5.16 Evacuation Time

The time (in hours) that is required to evacuate a nearby population from the vicinity of an accident location is entered under the keyword EVACUATION.[6] The time is composed of (a) response time (i.e., the time it takes responders to reach the accident site, assess the hazard and initiate evacuation), and (b) actual evacuation time. The STANDARD value is 24 h. Evidence exists, however, to support use of a considerably lower value. A distribution of actual evacuation times from actual hazardous materials accidents is given in Mills, Neuhauser, & Smith (1995), and the mode (the "mean" of a log-normal distribution) is approximately 1 hour. Using Latin Hypercube Sampling (LHS) methods (Iman & Shortencarier, 1984) to sample from this distribution or a similar one developed by the user is the best way to deal with the uncertainty in this parameter (see Mills, Neuhauser & Kanipe (1995) for applications of LHS to RADTRAN).

5.17 Post-Accident Options

RADTRAN 5 contains decision logic that is based on calculated ground deposition and user-defined action thresholds. There are three possible courses of action:

1. If the ground deposition (Ci/m^3) exceeds the minimum clean-up level (keyword CULVL, Section 3.6), then the area under the plume is modeled as being evacuated at the end of the time entered under keyword EVACUATION (see Section 4.4);
2. If the ratio of ground deposition to clean-up level exceeds the maximum threshold (keyword INTERDICT), then the area is modeled as being permanently interdicted. That is, no residents return to the area and no additional dose is accumulated by these residents beyond what was already received in the hours prior to evacuation;
3. If the first but not the second threshold value is exceeded, then the area is modeled as being cleaned-up to acceptable levels, after which returning population are modeled as being chronically exposed to residual material at the action-threshold level.

As noted previously, the STANDARD value of the time required for surveying potentially contaminated areas (keyword SURVEY) is 10 days, which is less, probably considerably less, than such an activity would be expected to take in reality (Chanin & Murfin, 1996). However, in view of the uncertainty in estimating this parameter value, the short 10-day value has been used because it is *radiologically conservative*; that is, it minimizes time for radioactive decay and thereby maximizes exposure from any short-lived isotopes at all subsequent times. The time required for clean-up is not explicitly accounted for, but actual clean-up times are most likely to be years or even decades (Chanin & Murfin, 1996). Because it is assumed that cleanup would always result in subsequent exposure of returning population to contamination at the minimum action-threshold level, however, actual clean-up time does not greatly influence the population-dose calculation.

5.18 Output Options

There are two output formats: dose and health-effect. Both types of output are usually desired for an analysis. ➡***Radiological risks should always be presented at a minimum in the dose format (expected population dose-risk) since it is the least derivative of the two values.*** Expected health effects (e.g., latent cancer fatalities) may be obtained by a second run of the code or by calculations

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[6] The term "evacuation" in RADTRAN refers collectively to activities separately labeled as "evacuation" and "relocation" in the MACCS code used by the NRC for fixed site analysis.

external to the code. In both output options, early radiological fatality and nonradiological fatality calculations are always performed.

The population-dose output format is selected on the FORM menu screen. Workstation users should enter the keyword UNIT on the FORM line. Doses are calculated for the exposure pathways shown in the box. Three of the dispersion-pathways results are what are called "prompt" doses. That is, doses that occur during or within a few hours of cloud passage. They are cloudshine, inhalation, and groundshine during evacuation. For each isotope in a material, effective dose equivalents for inhalation, cloudshine, and ingestion are taken from the radionuclide library. Groundshine and LOS doses are calculated from isotope-specific photon-energy data (except for LOS doses for special-form materials, see Section 5.3.4). The resuspension pathway is merely a delayed, chronic inhalation pathway, corrected when necessary for clean-up, weathering, and radioactive decay.

Box 5-1

RADTRAN 5 Exposure Pathways

Direct Exposure to Package
Loss of Shielding (LOS)
and
5 Dispersion Pathways:
Cloudshine
Inhalation
Groundshine
Resuspension
Ingestion (societal)

The health-effects output format may be selected by either selecting it on the FORM menu screen or entering the keyword NONUNIT. If NONUNIT is selected, then STANDARD values of health-effects multipliers may be used for latent-cancer fatalities and hereditary disorders, or the user may supply others. As noted in Chapter 4, health-effects risks are given for each route segment and for each exposure pathway. Tables give the risks related to loss-of-shielding exposures, all dispersion-related exposures except ingestion, and societal ingestion. The conversion factors, e.g. LCF per person-rem, are listed in the tabulations of input data. ➨***If the stop model is used to perform an LOS analysis, then the user must estimate early effects (morbidities and mortalities) externally.***

5.19 Early Effects

Early or deterministic health effects only occur at high radiation doses. Their severity increases with increasing dose, and a threshold exists below which no effect is observed. They also may be called acute, deterministic, or prompt effects. Persons in close proximity to intense gamma and/or neutron sources during a loss-of-shielding accident could receive acute doses above the effects' thresholds; as could persons in the innermost isopleths who are exposed via the inhalation or groundshine pathways following a dispersal accident. Symptoms may appear within a few hours or days following exposure. Depending on dose, effects exhibit a range of severity from short-term anorexia or vomiting, hair loss, and erythema (skin reddening), which are accounted for in the morbidity estimates, up to and including mortality, which is accounted for separately.

5.19.1 Mortality

Mortality may be observed in a fraction of a population exposed to high doses delivered over short periods of time. Death may occur in days, weeks or months, depending on the magnitude of the dose, post-exposure medical treatment, and initial health status of the affected individual(s). The likelihood of mortality decreases if the dose is fractionated or protracted (ICRP, 1984). The 1-year dose is calculated and used to estimate mortalities in RADTRAN 5. The probability of death for a given acute bone marrow or lung dose is listed in an internal data table in RADTRAN 5 (see Table 5-2). This table is used to estimate mortality associated with doses calculated in an analysis. The data are derived from Evans et al. (1985) and are consistent with those used in the MACCS2 code. A mortality estimate is performed and printed regardless of the output option selected.

5.19.2 Morbidity

Morbidities or non-lethal clinical effects are also estimated in RADTRAN 5. As in previous releases of RADTRAN, several organ-specific effects are evaluated for the inhalation pathway. The organs included are:

- Lung

- Upper Gastrointestinal Tract (stomach)
- Bone Marrow
- Thyroid (radioiodine only)

The bone marrow and upper GI tract (stomach) are relatively radiosensitive, and the morbidity thresholds are lowest for these two organs. Lung tissue is among the most radiation resistant, and it has the highest morbidity threshold. Thyroid morbidity (noncancerous nodules and hypothyroidism) results almost exclusively from intake of radioiodine.

Table 5-1 – Mortality – Dose Relationship for Marrow and Lung Exposure

Marrow Dose (rem)	Fatality Incidence	Marrow Dose (rem)	Fatality Incidence	Lung Dose (rem)	Fatality Incidence
<160	0.00000	570	0.99482	<500	0.00000
160	0.00913	580	0.99679	525	0.00759
170	0.01234	590	0.99808	550	0.01050
180	0.01639	600	0.99889	575	0.01430
190	0.02143	610	0.99938	600	0.01922
200	0.02761	620	0.99967	625	0.02549
210	0.03510	630	0.99983	650	0.03341
220	0.04408	640	0.99992	675	0.04329
230	0.05475	650	0.99996	700	0.05548
240	0.06729	660	0.99998	725	0.07038
250	0.08188	6700	0.99999	750	0.08837
260	0.09872	>670	1.00000	775	0.10988
270	0.11797			800	0.13529
280	0.13977			825	0.16498
290	0.16425			850	0.19925
300	0.19150			875	0.23830
310	0.22155			900	0.28218
320	0.25438			925	0.33077
330	0.28990			950	0.38372
340	0.32798			975	0.44042
350	0.36838			1000	0.50000
360	0.41078			1025	0.56130
370	0.45481			1050	0.62293
380	0.50000			1075	0.68335
390	0.54583			1100	0.74095
400	0.59172			1125	0.79420
410	0.63706			1150	0.84178
420	0.68123			1175	0.88274
430	0.72363			1200	0.91656
440	0.76371			1225	0.94326
450	0.80096			1250	0.96331
460	0.83499			1275	0.97755
470	0.86552			1300	0.98709
480	0.89237			1325	0.99306
490	0.91551			1350	0.99653
500	0.93502			1375	0.99840
510	0.95111			1400	0.99933
520	0.96406			1425	0.99974
530	0.97423			1450	0.99991
540	0.98199			1475	0.99997
550	0.98776			1500	0.99999
560	0.99192			>1500	1.00000

5.20 Unit-Risk Factors

The Unit-Risk Factor Method was developed in the early 1980s by Sandia National Laboratories, which also performed the first analyses in which this method was used (Wilmot et al., 1983; Neuhauser et al., 1984; Cashwell et al., 1986). Other analyses in which it has been used include DOE (1995). The method remains suitable for certain applications, such as comparisons of alternative packagings and content loading.

A unit-risk factor is defined as a quantitative risk (e.g., dose-risk, fatality-risk) associated either with transportation of a given shipment for a unit distance of travel, usually 1 km, or with a unit activity, e.g. one handling. The approach is useful when the user wishes to evaluate a large number of alternatives that differ from each other in only one or a very few package-related or route-related features.

To develop route-level unit-risk factors, reasonably consistent *route subclasses* must be identified. A route subclass can be defined as an aggregate of all portions of a route that have some property or combination of properties in common. The term "property" means a route-related RADTRAN variable (e.g., population density between a specified range, traffic count within a specified range, etc.). The most common route subclasses are based on population density (rural, suburban, and urban) [see Section 4.4.1]. A maximum of 60 subclasses per run may be defined by the user.

Unit-risk factors (URFs) are calculated for each route subclass with input data that are held constant for all other parameters including mode and shipment type. The number of shipments should be set to unity. The result should be a set of unit-risk factors expressing dose-risk (or, less desirably, health risk) per unit of travel for a single shipment in each route subclass for:
1. incident-free dose to transportation workers,
2. incident-free dose to the public,
3. accident risk,
4. non-radiological fatality risk from ordinary accidents.

They can be combined in an external calculation to express a unit shipment risk. URFs are shipment specific, and must be recalculated for each shipment variation such as radionuclide inventory or package type even if all other characteristics of the proposed transportation are the same.

The user can analyze a route by this method without having to go through the expensive process of gathering detailed data on individual routes. However, the unit-risk-factor technique cannot achieve a high level of resolution and is best suited for Programmatic Environmental Impacts Statements and similar types of high-level or generic studies. ➨**Great care must be taken to apply the URF technique appropriately.** For example, if a given material may be shipped by one mode in two distinct types of packagings with differing capacities, then the URFs for the low-capacity package are likely to be the smallest. However, an increased number of shipments would be required to transport the same amount of material to the same destination with the low-capacity packaging. Therefore, the *total* or campaign-level risk [Σ (URF_r x km_r, where r = route subsets 1 through r) x Number of Shipments] associated with use of the low capacity packaging could easily exceed that associated with use of the high-capacity packaging. The total risk comparison must be performed external to RADTRAN. If the comparison were omitted or the risks improperly calculated, then one might incorrectly conclude that the small package presented the lowest risk alternative. ➨**External calculations are not covered by RADTRAN software QA, and it is incumbent on the user to demonstrate their correctness**. One should also note that it is illogical and improper to calculate a unit-risk factor below the single-shipment level (e.g., for a single radionuclide in a shipment).

Radiological unit-risk factors could not be used in the absence of a linear-no-threshold (LNT) hypothesis. The LNT hypothesis for health effects of radiation exposure is currently being reexamined by various national and international bodies. Should it cease to be the preferred hypothesis, URFs could no longer be used, at least in their present form, to assess radiological impacts of RAM transportation.

Unit-risk factors for nonradiological fatalities do not suffer from a similar dependency on a linear hypothesis, with the exception of the so-called incident-free factor, which was intended to account for health effects of inhalation of diesel exhaust. The factor values were originally assigned on the basis of a rather generic assessment by Rao et al. (1981) in which an LNT relationship was assumed.[7] Beginning at about the same time, the effects of many components of diesel exhaust (e.g., benzene) had begun to be better characterized (Wark and Warner, 1981). Exposure thresholds have now been identified for most of these components (e.g., 10ppm for benzene; see Calabrese and Kenyon, 1991). In view of these developments, the use of an incident-free risk factor for nonradiological fatalities based on an LNT hypothesis can no longer be justified. ➨**Therefore, no STANDARD value has been recommended for the incident-free risk factor for nonradiological fatalities in RADTRAN 5, and the variable may be removed in a future release of the code.**

[7] Values were assigned for urban areas only and were 1.0E-07 fatalities/vehicle-km for highway, 1.3E-07 fatalities/vehicle-km for commercial rail, and 6.5E-07 fatalities/vehicle-km for dedicated rail.

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7 APPENDIX A Glossary of Terms

Many of the definitions given in this section are taken from ***The Health Physics and Radiological Health Handbook*** (Shleien, 1992). Some have been abridged or otherwise edited.

Absorbed dose---The energy imparted by *ionizing radiation* per unit mass of irradiated material. The units of absorbed dose are the *rad* and the *gray*.
Activity Mean Aerodynamic Diameter (AMAD)---The diameter of a unit-density sphere with the same terminal settling velocity in air as that of an aerosol particle the radioactivity of which is the median for the entire aerosol.
Air modes---Carriage of *packages* by *cargo air craft* or *passenger air craft*.
Atom---The smallest particle of an element that cannot be divided or broken up by chemical means. An atom consists of a nucleus, which contains protons and *neutrons*, and *electrons* that orbit the nucleus.
Attenuation---The process by which a beam of radiation is reduced in intensity when passing through some material.
Attenuation Coefficient---Of a substance, for a parallel beam of specified radiation: the quantity μ in the expression μdx for the fraction removed by attenuation in passing through a thin layer of thickness dx of that substance. The *linear attenuation coefficient* is expressed in terms of length (meters).
Beta radiation---Charged particles emitted from atomic nuclei during *radioactive decay*. A negatively charged beta particle is identical to an *electron*.
Cask---A heavily shielded accident-resistant container (*packaging*) used to ship and/or store highly *radioactive materials* such as *spent fuel*.
Cargo air mode---Carriage of *packages* by cargo aircraft.
Carrier---A company engaged in the transportation of passengers or property by land or water as a common, contract, or private carrier, or by civil aircraft.
Cloudshine---Gamma radiation from airborne materials in an airborne plume.
Collective Dose---The sum of the individual *doses* received in a given period of time by a specified population from exposure to a specified source of *radiation*.
Committed Dose Equivalent---The dose equivalent to organs and tissues that will be received from an intake of radioactive material by an individual during the 50-year period following the intake. The ICRP defines this as the committed equivalent dose.
Committed Effective Dose---See *committed effective dose equivalent.*
Committed Effective Dose Equivalent (CEDE)---The sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the *committed dose equivalent* to these organs or tissues. The ICRP defines this as the *committed effective dose.*
Contamination---The deposition of unwanted radioactive material on the surfaces of structures, areas, objects, or personnel.
Conveyance---Any *vehicle, vessel* or *aircraft* that might be used for the transportation of *radioactive material*.
Crud---A colloquial term for corrosion and wear products (rust particles, etc.) that become *radioactive* under a radiation flux. Sometimes found on the exterior surfaces of *spent fuel*. Derived from the term Chalk River Unidentified Deposits, which relates to the Chalk River reactor in Canada where crud was first observed.
Cumulative Dose---The total dose resulting from repeated exposures to *radiation* of the same region or of the whole body over a period of time.
Curie---A unit used to describe the intensity of *radioactivity* in a material. The curie is equal to 37 billion disintegrations per second, which is approximately the rate of decay of 1 gram of radium. Named for Marie and Pierre Curie who discovered radium in 1898.
Daughter Products---*Radionuclides* that are formed by the *radioactive decay* of some other radionuclide.
Decay, Radioactive---The decrease in the amount of any *radioactive* material with the passage of time, due to the spontaneous emission from the atomic nuclei of either alpha or *beta* particles, often accompanied by *gamma radiation*. (See *half-life; radioactive*)
Decontamination---The reduction or removal of contaminating radioactive material from a structure, area, object, or person.

Dose or Radiation Dose---A generic term that means *absorbed dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent,* or *total effective dose equivalent.*
Dose Equivalent---The product of the *absorbed dose*, the *quality factor*, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and sievert (Sv).
Dose Rate---The *radiation dose* delivered per unit time. E.g., rem per hour.
Effective Dose Equivalent---The sum of the products of the dose equivalent to the organ or tissue and the *weighting factors* applicable to each of the organs or tissues that are irradiated.
Electron---An elementary particle with a unit negative charge. See *beta radiation*.
Element---One of the 103 known chemical substances that cannot be broken down further without changing its chemical properties. Examples are hydrogen, nitrogen, gold, lead, and uranium.
Evacuation---The urgent removal of people from an area to avoid or reduce high-level, short-term exposure, usually from an airborne plume or from deposited activity.
Exclusive-use--- A term used to describe a shipment in which the conveyance carries radioactive-material packages exclusively and no other cargo.
Exposure---A measure of the ionization produced in air by X or gamma radiation; units of exposure in the air are the Roentgen or coulomb per kilogram (SI units).
Fission Gases---Those fission products that exist in the gaseous state. Primarily the *noble gases* (krypton, xenon, radon, etc.)
Flux---A term applied to the amount of some type of *radiation* crossing a certain area per unit time. The unit of flux is number of particles, photons, etc. per square centimeter per second.
Gamma Radiation---High-energy, short wavelength electromagnetic radiation emitted from the nucleus of an atom. Gamma radiation frequently accompanies alpha and beta particle emissions and always accompanies fission. Gamma rays are very penetrating and are best stopped or shielded against by dense materials such as lead or uranium.
Gaussian---Pertaining to or having properties of the probability density function that is also called the Normal Distribution or bell curve; named after 19th Century German mathematician Karl F. Gauss.
Genetic Effect---An effect in a descendant resulting from the modification of genetic material in a parent.
Gray (Gy)---The SI unit of *absorbed dose*. One gray is equal to an absorbed dose of 1 Joule per kilogram (100 *rad*).
Groundshine---Gamma radiation from radioactive materials deposited on the ground.
Half-life---The time in which half the atoms of a particular *radioactive* substance disintegrate to another nuclear form.
Health Effects---See *stochastic effects* and *nonstochastic effects*.
Ion---An *atom* that has too many or too few *electrons*, causing it to be chemically active.
Ionizing radiation---Any *radiation* capable of displacing electrons from atoms or molecules, thereby producing *ions*. Includes: alpha, beta, gamma, X-rays, neutrons, and ultraviolet light.
Isotope---One of two or more atoms with the same number of protons, but different number of neutrons, in their nuclei. Isotopes have very nearly the same chemical properties, but very often different physical properties (for example, carbon-12 and -13 are *stable*, carbon-14 is *radioactive*).
Joule (J)---A unit of energy equal to 1 watt-second or .239 calories. Named after English physicist James P. Joule (1818-1889).
Linear Attenuation Coefficient---See *attenuation coefficient*.
Maritime modes---See *Waterway modes.*
Member of the Public---An individual in an unrestricted area. An individual is not a member of the public during any period in which the individual receives an *occupational dose*.
Molecule---A group of *atoms* held together by chemical bonds. A molecule is the smallest unit of a compound that can exist by itself and retain all its chemical properties.
Neutron---An uncharged elementary particle found in the nucleus of every *atom* heavier than hydrogen.
Noble Gas---A gaseous chemical element that does not readily enter into chemical combination with other elements. An inert gas. (See *fission gases*)
Nonstochastic effects---Health effects, the severity of which varies with the dose and for which a threshold is believed to exist (also called deterministic, early, or prompt effects). Usually follow exposure within a few hours or days; effects range from short-term nausea and skin-reddening up to, for supralethal doses, death within a few days.
Nuclide---A general term referring to all known isotopes, both *stable* and *unstable,* of a chemical *element*. See also *radionuclide*.

Occupational Dose---The dose received by an individual in a restricted area or in the course of employment in which the individual's assigned duties involve exposure to radiation and to radioactive material from licensed and unlicensed sources of radiation, whether in the possession of the licensee or other person.

Overland modes of transportation---Carriage of *packages* by *highway* or *rail* modes.

Package---A *packaging* and its *radioactive* contents.

Packaging---The assembly of components necessary to ensure compliance with packaging requirements. It may consist of one or more receptacles, absorbent materials, spacing structures, thermal insulation, radiation shielding, and devices for cooling or absorbing mechanical shocks. The *vehicle*, tie-down system, and auxiliary equipment may be designated as part of the packaging.

Parent---A *radionuclide* that upon *radioactive decay* or disintegration yields another nuclide (the *daughter*).

Pasquill System---Also called the Pasquill-Gifford System. A widely used empirical system for assigning Gaussian diffusion parameters to atmospheric releases of pollutants, including radionuclides. Six classes of atmospheric stability may be specified in RADTRAN 5; they range from highly unstable (Class A) to moderately stable (Class F). The frequency of occurrence of each class is recorded by many weather stations.

Passenger air mode---Carriage of *packages* by passenger aircraft.

Photon---A quantum (or packet) of energy emitted in the form of *radiation*. *Gamma rays* and X-rays are examples of photons.

Point Source---Ideally, a source with infinitesimal dimensions. Practically, a source of radiation the dimensions of which are small compared with the viewing distance.

Public Dose---The population *dose* received by *members of the public* from exposure to *radiation* and to radioactive material. It does not include *occupational dose*.

Pressurized Water Reactor (PWR)---A power reactor in whch heat is transferred from the core to a heat exchanger by high-temperature water kept under high pressure.

Quality Factor---The modifying factor that is used to derive *dose equivalent* from *absorbed dose*.

Rad--- A unit of *absorbed dose*. One rad is equal to an absorbed dose of 100 ergs/gram or 0.01 J per kg (0.01 gray).

Radiation (ionizing radiation)---*Alpha* particles, *beta* particles, *gamma* rays, X-rays, *neutrons* and other particles capable of producing *ions*.

Radioactive---Exhibiting *radioactivity*.

Radioactive Decay---See *Decay, radioactive.*

Radioactive Isotope---A *radioisotope*.

Radioactivity---The spontaneous emission of *radiation*, from the nucleus of an unstable *isotope*.

Radioisotope---An unstable *isotope* of an *element* that *decays* or disintegrates spontaneously, emitting *radiation*.

Radionuclide--- A general term referring to all known *unstable* or *radioactive* isotopes of a chemical *element.* A *radioisotope*.

Rail mode---Carriage of one or more *packages* by one or more railcars in a train traveling on a railroad.

Reference Man---A hypothetical aggregation of human physical and physiological characteristics arrived at by international consensus. These standards are used to relate biological insult from radiation to a common base.

Rem---A unit of *dose equivalent.* The *dose equivalent* in rem is equal to the *absorbed dose* in *rad* multiplied by the *quality factor* (1 rem = 0.01 sievert). Rem was originally an abbreviation for "Roentgen equivalent man (or mammal). See also *sievert.*

Shielding---Any material or obstruction that absorbs *radiation* and thus tends to protect persons or materials from the effects of *ionizing radiation.*

Short-lived daughters---*Radioactive* progeny of *radioactive isotopes* that have *half-lives* on the order of a few hours or less.

Sievert (Sv)---The SI unit of *dose equivalent.* The dose equivalent in sieverts is equal to the *absorbed dose* in *gray* multiplied by a *quality factor* (1 Sv = 100 *rem*).

Spent Fuel (spent nuclear fuel)---Nuclear reactor fuel that has been used to the extent that it can no longer effectively sustain a chain reaction; also applied less accurately to fuel that has been used to any extent in a reactor and permanently removed from the reactor.

Stable Isotope---An *isotope* that does not undergo *radioactive decay*.

Stochastic Effects---Health effects that occur randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold. Genetic effects and cancer incidence are examples of stochastic effects of exposure to radiation.
Survey---An evaluation of the radiological conditions and potential hazards incident to the release or presence of *radioactive material*. When appropriate, such an evaluation includes a physical survey of the location of radioactive material and measurements or calculations of levels of radiation or concentrations or quantities of radioactive material present.
Transport Index (TI)--- A dimensionless number, rounded up to the first decimal place, placed on the label of a package to designate the degree of control to be exercised by the carrier during transportation. The TI is derived from the maximum radiation level in millirem per hour at 1 meter from the external surface of the package.
Truck---Any of several types of *vehicles* used in the carriage of *packages* by *highway mode*
Unstable Isotope---A *radionuclide* or *radioisotope*.
Unit-Risk Factor---A risk (e.g., dose-risk, fatality-risk) associated with transportation of a given radioactive material shipment for a unit distance of travel, usually 1 km.
Van---Any of a class of medium-sized *vehicles* often used for the carriage of small *packages* such as radiopharmaceuticals by *highway mode*.
Vehicle---Motorized *conveyance* used for transportation of *packages* by *highway* mode. *Trucks* and *vans* are vehicles.
Vessel---Any conveyance used for the transportation of *packages* by *waterway modes*. *Ships* and *barges* are vessels.
Waterway Modes---Carriage of *packages* by *barge* or *ship* (also called *maritime modes*).

8 APPENDIX B Intermediate Data and Plots

Ordered pairs of probability and consequence values are written to output files R5PLOT0.DAT, R5PLOT1.DAT and R5PLOT2.DAT. These files contain, respectively, dose or latent-cancer-fatality (LCF) estimates, genetic-effects estimates, and maximum-individual-dose estimates. Associated summed probabilities are also included in these files. R5INTERM.DAT contains all of the data necessary to produce each of these files. These data can be used for probability-consequence plotting and sensitivity analysis. R5INTERM.DAT is intended to preserve the numerous intermediate probability and consequence calculations that are performed in RADTRAN 5 prior to the generation of the ordered-pair files and the final products and summations which are the actual risk values. Additional features of the ordered-pairs files are implemented by the subroutine PAIRS, which reads consequence and probability data from R5INTERM.DAT by using keywords within the file to locate the data. The probabilities are link-specific, and the consequence types are dispersion-cloud-specific. This means that for each link analyzed, up to six separate dispersion clouds and associated sets of consequence values, corresponding to up to six Pasquill atmospheric stability categories, may be given for each consequence type. Corresponding probability arrays also are constructed. If the pre-calculated Pasquill dispersion clouds are used, then each probability value is multiplied by the appropriate Pasquill probability. If the Pasquill dispersion data are not used, then a single set of dispersion data is used.

For each link in a given analysis, the accident rates are written to R5INTERM.DAT. The total number of expected accidents for all shipments is written for each link. A record is written for each radionuclide in each material for each mode in the link. The record gives estimates of either dose or latent cancer fatalities, genetic effects, and maximum individual consequences. The expected numbers of accidents and Pasquill categories are given at the link level, whereas dose and health-effects estimates are calculated at the radionuclide-level.

The order in which the values are written to the file R5INTERM.DAT is as follows:

> The first number in the file R5INTERM.DAT is the number of severity categories (NSEV) used in the analysis to describe the spectrum of accidents. The descriptor line PASQUILL CATEGORY AND PROBABILITY is followed by the Pasquill category number and the fraction; if the run is not a Pasquill run then the category number will be 1 and be assigned a fraction of 1.0. Descriptor line LINK is followed by the link number, the vehicle identifier, and the vehicle number, then the descriptor ACCIDENT RATE followed by the accident rate multiplied by the severity fraction. There will be NSEV values. Next is the descriptor EXPECTED NUMBER OF ACCIDENTS (PROBABILITY) which is then followed by the accident rate multiplied by the product of the distance traveled and the number of shipments. Again, there will be NSEV values. Descriptor lines ISOTOPES are listed after the LINK descriptor. Each ISOTOPES descriptor is followed by the isotope number, the curie value times the number of packages, and the half-life of the isotope. The next line lists the nuclide name, the physical-chemical group to which it was assigned, and the material in which it is contained. For each radionuclide there are 3 associated descriptors. The first is LCF (NON-UNIT) OR PERSON-REM (UNIT) CONSEQUENCE DATA. The values for this descriptor are, as indicated, either latent cancer fatality data or person-rem dose vales for each severity category. The next descriptor is GE CONSEQUENCE DATA. The values following this will be zero if health effects output was not chosen. Otherwise; the genetic effects data will be listed for each severity category. Finally, the descriptor MAXIMUM INDIVIDUAL DOSE is listed followed by maximum individual dose consequences for each severity category.

The above order is repeated for each Pasquill category if the run uses the Pasquill atmospheric dispersion option. Each link is listed and within each link all radionuclides are listed with their associated descriptors and values. Below is an example of the subroutine PAIRS which is used to produce the probability-consequence pairs in files R5PLOT0.DAT, R5PLOT1.DAT and R5PLOT2.DAT. PAIRS is written so that it can be used as a stand-alone program.

```
      SUBROUTINE PAIRS
C       PROGRAM PAIRS
C
```

```
C     THIS SUBROUTINE (PROGRAM) READS IN DATA FROM R5INTERM.DAT
C      PRODUCED BY
C     RADTRAN AND PRODUCES 3 FILES OF ORDERED PAIRS OF NUMBERS.
C     THE FIRST NUMBER IS A CONSEQUENCE AND THE SECOND IS A SUMMED
C     PROBABILITY.  THE SUMMED PROBABILITIES INDICATE THE PROBABILITY
C     OF A PARTICULAR CONSEQUENCE OR WORSE.  CONSEQUENCES WITH
C     ZERO PROBABILITIES ARE IGNORED AND NOT PRINTED.
C     1. R5PLOT0.DAT CONTAINS SORTED LCF OR PERSON-REM CONSEQUENCES
C        WITH SUMMED PROBABILITIES.
C     2. R5PLOT1.DAT CONTAINS SORTED GENETIC EFFECTS CONSEQUENCES
C        WITH SUMMED PROBABILITIES.
C     4. R5PLOT2.DAT CONTAINS SORTED MAXIMUM INDIVIDUAL DOSE
C      CONSEQUENCES WITH SUMMED PROBABILITIES.
C
C .... 20*60*6=7200    SEVERITIES*LINKS*PASQUILL CATEGORIES

      PARAMETER (LENGTH=7200)

      REAL CONLCF(LENGTH), CONGE(LENGTH), CONMAX(LENGTH)

C .... CONLCF > CONSEQUENCE OF LCF (OR PERSON-REM)
C .... CONGE  > CONSEQUENCE OF GENETIC EFFECTS
C .... CONMAX > CONSEQUENCE OF MAXIMUM INDIVIDUAL DOSE

      REAL CLCF(20), CGE(20)

C .... TEMPORARY VARS TO HOLD EACH ISOTOPE'S NSEV VALUES FOR LCF AND C
GE

      REAL PRLCF(LENGTH), PRGE(LENGTH), PRMAX(LENGTH)

C .... PRLCF  > PROBABILITY OF LCFs (OR PERSON-REM)
C .... PRGE   > PROBABILITY OF GENETIC EFFECTS
C .... PRMAX  > PROBABILITY OF MAXIMUM INDIVIDUAL DOSE

      CHARACTER TEST*10

      REAL DUMMY(20), PROB(20), PASQPR
C .... PROB HOLDS THE PROBABILITY FOR A LINK
C .... PASQPR HOLDS THE PASQUILL PROBABILITY (WILL BE 1.0 IF
C .... PASQUILL NOT USED IN RADTRAN)

      LOGICAL EOF
      DATA EOF / .FALSE. /

C .... COMMENT OUT NEXT LINE IF USED AS A SUBROUTINE INSIDE RADTRAN
C      OPEN (UNIT=8, STATUS='OLD', FILE='R5INTERM.DAT')
      REWIND (8)
      OPEN (UNIT=10, STATUS='UNKNOWN', FILE='R5PLOT0.DAT')
      OPEN (UNIT=11, STATUS='UNKNOWN', FILE='R5PLOT1.DAT')
      OPEN (UNIT=12, STATUS='UNKNOWN', FILE='R5PLOT2.DAT')

   10  CONTINUE
C ...  CONTINUE READING R5INTERM.DAT - FOR SEPARATE RUNS

      READ (8,'(I5)',END=1000) NSEV
      LOOP = -1
C .... LOOP KEEPS TRACK OF THE NUMBER OF DIFFERENT OUTPUT GROUPS
```

```
C      DIFFERENT VEHICLES AND/OR DIFFERENT PASQUILL CATEGORIES)
C       STARTS AT ZERO
      DO 15 I = 1, LENGTH
        CONLCF(I) = 0.0
        CONGE(I) = 0.0
   15  CONTINUE

      IF (EOF) THEN
C ...... WRITE EOF TO THE OUTPUT FILES --- VARIABLE EOF WILL NOT BE TRUE
C ...... UNLESS A DATA SET HAS BEEN READ -- IF THERE IS ONLY ONE DATA SET
C ......OR IT IS THE LAST DATA SET THEN THE ABOVE READ WILL HAVE FOUND
C       THE END OF FILE. MARKER AND WOULD SKIP THIS AND GO TO THE END C
IN THIS WAY THERE WILL BE NO ENDING EOF AND NO EOF AT ALL FOR
C       JUST ONE DATA SET
        WRITE (10,'("       EOF")')
        WRITE (11,'("       EOF")')
        WRITE (12,'("       EOF")')
        EOF = .FALSE.
      ENDIF

   20  CONTINUE
C .... CONTINUE READING DATA FROM R5INTERM.DAT WHILE NOT EOF

       READ (8,'(A10)',END=1000) TEST

       IF (TEST.EQ.'       EOF') THEN
         EOF = .TRUE.

       ELSEIF (TEST.EQ.'      LINK') THEN
         READ (8,'()')
         READ (8,'()')
C . . . . SKIP THE ACCRAT ARRAY -- NOT USED FOR THIS APPLICATION
         READ (8, 100) (DUMMY(I),I = 1, NSEV)
         READ (8,'()')
         READ (8, 100) (PROB(I),I = 1, NSEV)
         LOOP = LOOP + 1

       ELSEIF (TEST.EQ.'  PASQUILL') THEN
         READ (8,'(I6,1PE10.2)') IDUM, PASQPR

       ELSEIF (TEST.EQ.'   ISOTOPE') THEN
         READ (8,'()')
         READ (8,'()')
         READ (8,'()')
         READ (8, 100) (CLCF(I), I = 1, NSEV)
         READ (8,'()')
         READ (8, 100) (CGE(I), I = 1, NSEV)

         DO 30 I = 1, NSEV
           PP = PROB(I)*PASQPR
           INDEX = LOOP*NSEV+I
           PRLCF(INDEX) = PP
           PRGE(INDEX) = PP
C . . . . . SUM THE COSEQUENCES OVER ISOTOPES
           CONLCF(INDEX) = CONLCF(INDEX) + CLCF(I)
           CONGE(INDEX) = CONGE(INDEX) + CGE(I)
   30    CONTINUE
```

```
      ELSEIF (TEST.EQ.'   MAXIMUM') THEN
        READ (8, 100) (CONMAX(LOOP*NSEV+I),I = 1, NSEV)

        DO 45 I = 1, NSEV
          PRMAX(LOOP*NSEV+I) = PROB(I)*PASQPR
  45    CONTINUE

      ELSE
        WRITE (10,'(A)') '  ERROR IN R5INTERM.DAT'
        WRITE (11,'(A)') '  ERROR IN R5INTERM.DAT'
        WRITE (12,'(A)') '  ERROR IN R5INTERM.DAT'
        STOP 'ERROR IN R5INTERM.DAT'
      ENDIF

      IF (.NOT.EOF) GOTO 20

C .... FOUND END OF A DATA SET IN R5INTERM.DAT

C
      LEN = (LOOP+1)*NSEV
C .... SORT BY CONSEQUENCE IN DECREASING ORDER CARRYING THE
C      PROBABILITY ALONG
      CALL SSORT (CONLCF, PRLCF, LEN, -2)
      CALL SSORT (CONGE, PRGE, LEN, -2)
      CALL SSORT (CONMAX, PRMAX, LEN, -2)

C .... SUM1 AND SUM2 HOLD PROBABILITY SUMS
      SUM1 = 0.0
      SUM2 = 0.0
      DO 50 I = 1, LEN
        IF (PRLCF(I).NE.0.0) THEN
C . . . . .SKIP IT IF THE PROBABILITY IS ZERO
          SUM1 = SUM1 + PRLCF(I)
          WRITE (10,200) CONLCF(I), SUM1
        ENDIF
        IF (PRGE(I).NE.0.0) THEN
C . . . . .SKIP IT IF THE PROBABILITY IS ZERO
          SUM2 = SUM2 + PRGE(I)
          WRITE (11,200) CONGE(I), SUM2
        ENDIF
  50  CONTINUE

      SUM1 = 0.0
      DO 70 I = 1, LEN
        IF (PRMAX(I).NE.0.0) THEN
C . . . . .SKIP IT IF THE PROBABILITY IS ZERO
          SUM1 = SUM1 + PRMAX(I)
          WRITE (12,200) CONMAX(I), SUM1
        ENDIF
  70  CONTINUE

      GOTO 10

 1000 CONTINUE
C .... END OF FILE MARKER WAS READ ....

  100 FORMAT (8(E10.3))
  200 FORMAT (2(1PE10.2))
```

```
C       STOP
      RETURN
      END
```

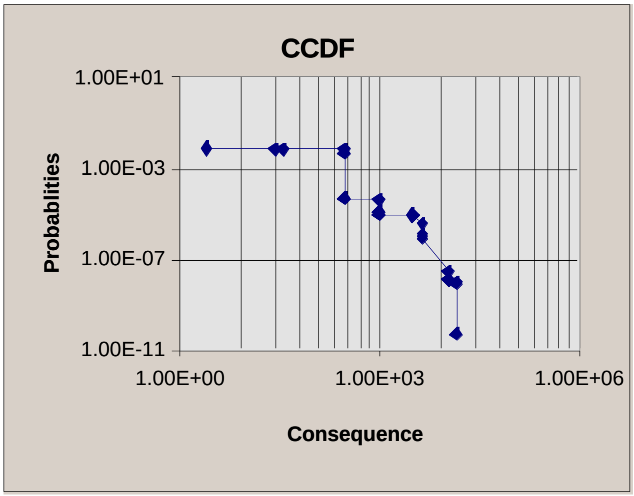
In the subroutine PAIRS, the consequence types are sorted and printed in decreasing order (highest first) and the corresponding probability array is re-ordered accordingly. When the consequences are printed, zero-probability consequences are omitted. The probabilities associated with each non-zero consequence are summed and printed at the same time that the consequences are printed. The resulting ordered pairs can be used for producing consequence-vs.-probability plots such as Cumulative Complementary Density Functions (CCDFs) in which the probability associated with each consequence represents the probability of the corresponding consequence being equal to or greater than the given value.

If the original output was requested in terms of dose rather than health effects, then doses will be written in R5PLOT0.DAT as indicated, but all consequence values in R5PLOT1.DAT will be zero and should be neglected. If R5INTERM.DAT contains more than one data set (indicated by the key word EOF after each data set), then each data set in R5PLOT0.DAT, R5PLOT1.DAT, and R5PLOT2.DAT will be separated by the word EOF. If there is only one data set, then no EOF is printed and all values in these files will be numeric.

To plot the values contained in the file R5PLOT0.DAT, R5PLOT1.DAT and R5PLOT2.DAT simply:

1. download the file (it is an ASCII text file),
2. open a spreadsheet program,
3. import the ASCII text file, and
4. create a plot using the program's capabilities.

An example is given below of a plot created from the R5PLOT0.DAT data loaded into the spreadsheet program, Microsoft Excel.™ The accompanying data table also was created by the spreadsheet program from the downloaded R5PLOT0.DAT file.



Sample Probability-Consequence Plot

Probability-Consequence Pairs Used in Sample Plot

CONSEQUENCE	PROBABILITY
1.41E+05	5.08E-10
1.41E+05	8.74E-08
1.41E+05	9.71E-08
1.41E+05	1.02E-07
1.06E+05	1.20E-07
1.06E+05	1.29E-07
1.06E+05	1.30E-07
1.06E+05	2.97E-07
4.34E+04	8.72E-06
4.34E+04	1.15E-05
4.34E+04	1.25E-05
4.34E+04	3.78E-05
3.27E+04	7.57E-05
3.27E+04	7.71E-05
3.27E+04	8.13E-05
3.27E+04	9.39E-05
9.85E+03	9.39E-05
9.85E+03	9.39E-05
9.85E+03	9.39E-05
9.85E+03	9.42E-05
9.85E+03	1.22E-04
9.85E+03	1.24E-04
9.85E+03	3.78E-04
9.85E+03	3.91E-04
3.03E+03	4.42E-04
3.03E+03	4.47E-04
3.03E+03	4.49E-04
3.03E+03	4.66E-04
3.03E+03	5.10E-02
3.03E+03	5.28E-02
3.03E+03	6.96E-02
3.03E+03	7.53E-02
3.63E+02	7.53E-02
3.63E+02	7.53E-02
2.73E+02	7.53E-02
2.73E+02	7.53E-02
2.53E+01	7.53E-02
2.53E+01	7.53E-02
2.53E+01	8.34E-02
2.53E+01	8.61E-02
0.00E+01	8.85E-02
0.00E+01	1.33E-01
0.00E+01	1.63E-01

Probability-Consequence Pairs Used in Sample Plot
(*continued)*

CONSEQUENCE	PROBABILITY
0.00E+01	1.64E-01
0.00E+01	1.78E-01
0.00E+01	5.16E-00
0.00E+01	7.70E-00
0.00E+01	1.53E+01
0.00E+01	1.57E+01
0.00E+01	1.67E+01
0.00E+01	1.73E+01
0.00E+01	1.89E+01
0.00E+01	2.06E+01
0.00E+01	2.08E+01
0.00E+01	2.08E+01
0.00E+01	2.12E+01
0.00E+01	2.14E+01
0.00E+01	2.20E+01
0.00E+01	2.23E+01
0.00E+01	2.31E+01

9 APPENDIX C Error Messages

The following is a listing of error messages for RADTRAN. This listing does not include device error messages that the user may receive from the system on which RADTRAN is installed. Device error messages are system-specific, and RADTRAN may be installed on a variety of systems. Many of the RADTRAN error messages are self-explanatory, but explanations are provided below to assist the user. Error messages appear in the main output file. In general, when an error occurs, the remainder of the output file will not be printed because calculation was terminated. With a few exceptions, which are noted below, recovery from RADTRAN errors consists of correcting value(s) in the input file and re-running RADTRAN.

ERROR MESSAGE LISTING IN ALPHABETICAL ORDER

AVINT INTEGRATION RETURNED ERROR = n

This message will only appear if there is an error within the SLATEC math routine AVINT. If this message appears, the copy of the code being used may have been corrupted. In this event, please contact the code developer, Sandia National Laboratories.

CAN ONLY DEFINE A MAXIMUM OF n VEHICLES.

where

n = maximum number of vehicles allowed

User entered more than the maximum allowed number of vehicles under the keyword VEHICLE.

CONVERGENCE FAILED IN SUBROUTINE BESSL

The user should never receive this message during proper use of RADTRAN because the input parameters for the BESSL routine are not user-definable. If this message appears, the copy of the code being used may have been corrupted. In this event, please contact the code developer, Sandia National Laboratories.

DIMEN REQUIRES ONLY THREE VALUES

The three values are: number of severity categories, number of radial distances,and number of isopleth areas. The previous release of RADTRAN required 4 values after the keyword DIMEN, but RADTRAN 5 requires only the three values listed.

ERROR IN OPENING INGESTION FILE s

where

s = ingestion file name

The ingestion file name entered in the input file is incorrect. Either the file does not exist or the name is typed incorrectly. One should be aware that on a UNIX system filenames are *case sensitive.* If this message occurs with the file name given in the standard values data file, then the problem may be code-related. In this event, please contact the code developer, Sandia National Laboratories.

ERROR IN R5INTERM.DAT

If an error is encountered reading R5INTERM.DAT, then this error message is printed in R5PLOT0.DAT, R5PLOT1.DAT, and R5PLOT2.DAT.

ERROR IN PROBABILITIES FOR PASQUILL CATEGORIES x SUM = y

where

x = set of six values representing the frequencies of occurrence of the six Pasquill stability categories [x_1 x_2 x_3 x_4 x_5 x_6]; and
y = sum of the Pasquill probabilities.

This error message indicates that the sum of the probabilities of occurrence of the six Pasquill atmospheric stability categories is not equal to one. The sum of the probabilities of these categories must be adjusted to equal 1.0 before the code can run.

ERROR TOLERANCE NOT MET IN QUAD1

This message only appears if the limits of integration exceed the abilities of the QUAD1 subroutine. Since the user does not control these values, this message should not appear during proper use. If it does, then the copy of the code being used may have been corrupted. In this event, please contact the code developer, Sandia National Laboratories.

EXCEEDED NUMBER OF SEGMENTS ALLOWED

MAXIMUM NUMBER OF STOPS ALLOWED IS m_s
NUMBER OF STOPS ENTERED IS n_s

MAXIMUM NUMBER OF HANDLINGS ALLOWED IS m_h
NUMBER OF HANDLINGS ENTERED IS n_h

MAXIMUM NUMBER OF LINKS ALLOWED IS m_l
NUMBER OF LINKS ENTERED IS n_l

where

m = maximum number of stops (m_s), handlings (m_h), or links (m_l)
n = number of stops (n_s), handlings (n_h), or links (n_l)

Too many stops, handlings, or links were entered in the input file. The user must reduce the number of stops, handlings or links.

EXPECTED A NUMERIC VALUE, FOUND: s

where

s = character string read in from input.

This message appears if the user enters a character string instead of a numeric value where the latter is required.

FINDI FAILED ON BSKIN CALL

This message indicates that the user has input a value for μ (linear absorption coefficient), which is used in the gamma and neutron dose calculations, of less than zero. The coefficient must have a positive value.

FIRST KEYWORD MUST BE 'TITLE'. THE NEXT KEYWORD MUST THEN BE 'INPUT' WITH SECOND LEVEL KEYWORD 'STANDARD' FOR STANDARD DATA INPUT FILE, OR 'ZERO' FOR ZEROED OUT DATA INPUT FILE.

The user did not follow the required order for the first three lines of input in the input file.

FRACTIONS OF GAMMA AND NEUTRON MUST SUM TO 1.0
THE FRACTION OF GAMMA IS n AND THE FRACTION OF NEUTRON IS m

The sum of the fractions of the dose rate at 1 meter that are gamma and neutron radiations, respectively, must be 1.0. The user must adjust the values so that n + m = 1.0 before the code will run.

GOTO ERROR AT s

where

s = name of subroutine which had an error in a GOTO statement.

This message should not appear during proper use of RADTRAN. It indicates a programming error with a computed GOTO statement. If it does appear, then the copy of the code being used may have been corrupted. In this event, please contact the code developer, Sandia National Laboratories. .

GROUP s DOES NOT HAVE RELEASE FRACTIONS ASSIGNED ABOVE.

where

s = physical-chemical group name

User entered a physical-chemical group designator that had not been defined. The user must define a physical-chemical group under the keyword RELEASE before assigning release fractions, aerosol fractions, or respirable fractions to the group.

INVALID IACC VALUE IN EARLY

The IACC value is a flag used to indicate that a material contains dispersible (IACC = 2) or nondispersable (IACC = 1) isotopes. The user should never receive this message during proper use of RADTRAN because IACC is only set to 1 or 2. If this message should appear, contact the code developer (Sandia National Laboratories).

ISOTOPE NAMED s NOT DEFINED

where

s = isotope name

User entered an isotope name s that has not previously been defined. The user must define it under keyword DEFINE.

MATERIAL s NOT PREVIOUSLY DEFINED

where

s = material name

User entered a material name that had not previously been defined. The user must define it under keyword PACKAGE.

MATERIAL s PREVIOUSLY DEFINED

where

s = material name

User attempted to define a material under keyword PACKAGE with the same name as a material that has previously been defined.

MODE TYPE CANNOT BE ZERO

A mode type of 0 was entered. Allowable mode types are 1 through 10.

s IS INCLUDED IN PHOTON ENERGY OF PARENT ISOTOPE. TO INCLUDE THIS ISOTOPE SEPARATELY, PLEASE DEFINE USING ANOTHER SYMBOL COMBINATION.

where

s = isotope name

The user has attempted to define an isotope with a name that is a reserved word indicating that the isotope in question is a daughter product of one of the library isotopes. This is a precaution to prevent the user from unknowingly adding daughter products that have already been taken into account elsewhere. The user is not prevented from defining any isotope; however, the designator must differ from those in the daughter isotopes list.

THE DISTANCE FROM SOURCE TO CREW MEMBERS IS x METERS.
THE EFFECTIVE CHARACTERISTIC VEHICLE DIMENSION IS y METERS.
THE CREW DISTANCE MUST BE GREATER THAN 1/2 OF VEHICLE DIMENSION.

The distance from source to crew members is not large enough. Too small value for x will cause crew members to be effectively *inside* of the package; x must be > 1/2 y.

TOO MANY MATERIALS, MAX IS n

where

n = maximum number of materials allowed.

This message indicates that a new material name was entered that increased the number of materials to more than the maximum allowed. The user must delete at least one material from the input file.

TOO MANY ISOTOPES IN THE MATERIAL

This message appears when the user has included more isotopes in a material description than is allowed. All materials must be modeled as consisting of no more than 200 isotopes.

TOO MANY PHYSICAL-CHEMICAL GROUP TYPES, THE MAXIMUM IS n

where

n = maximum number of physical-chemical groups allowed.

This message indicates that a new physical-chemical group was entered that increased the number of groups to more than the maximum allowed. The user must delete at least one from the input file.

UNKNOWN IDENTIFIER DETECTED ON INPUT s

where

s = character string read in from input.

This message appears when a character string that is not a keyword has been used in a keyword location. This message can result from either a spelling error or improper location of the character string.

VALUE ENTERED IS x,
VALUE MUST BE GREATER THAN OR EQUAL TO y

where

x = input value entered by the user
y = maximum value allowed

The message appears when the input file contains a value that is not within the prescribed allowable range for a particular variable. In the output file the line that is echoed just before this message will contain the erroneous value.

VALUE ENTERED IS x,
VALUE MUST BE LESS THAN OR EQUAL TO y

where

x = input value entered by the user
y = maximum value allowed

The message appears when the input file contains a value that is not within the prescribed allowable range for a particular variable. In the output file the line that is echoed just before this message will contain the erroneous value.

VEHICLE s NOT PREVIOUSLY DEFINED

where

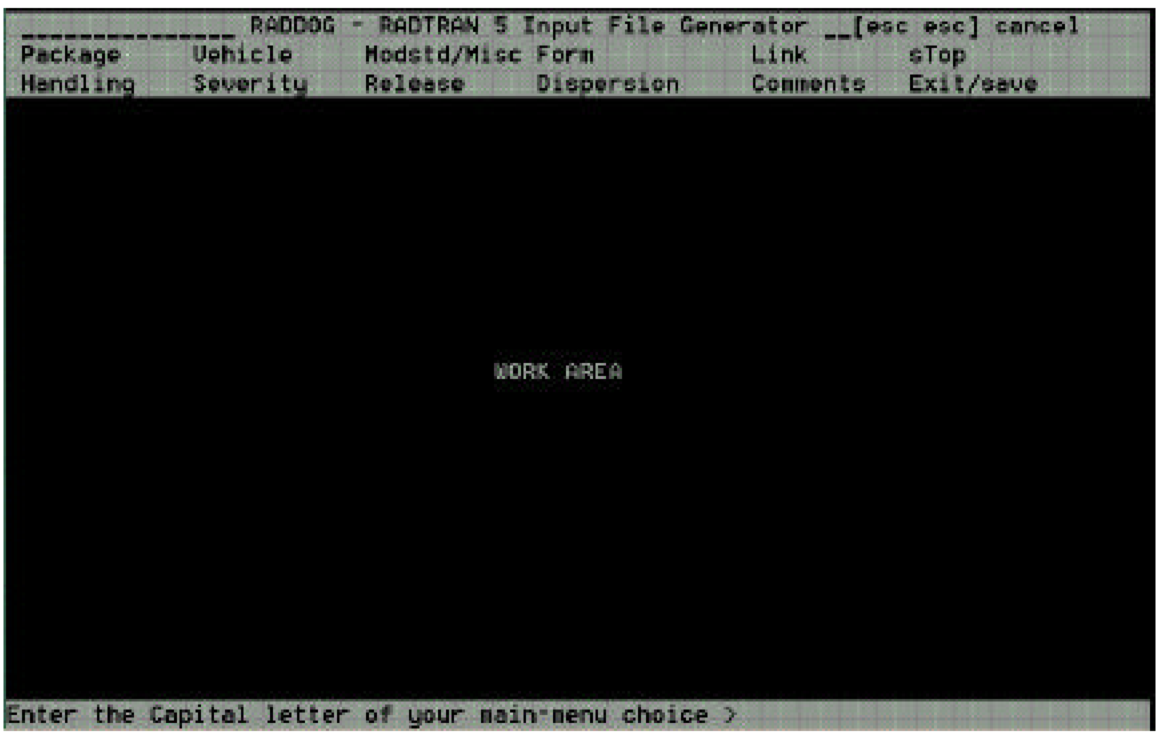
s = vehicle name

An attempt was made to enter a vehicle name that had not previously been defined under keyword VEHICLE.

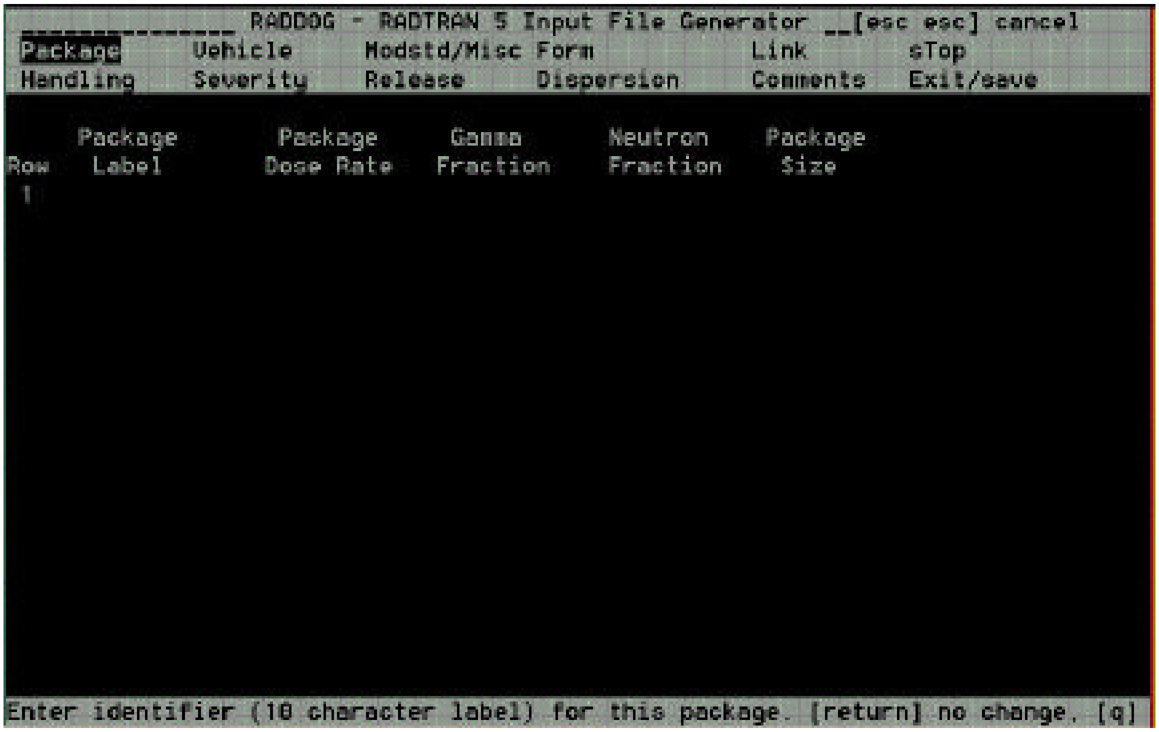
10 APPENDIX D RADDOG Screens

The main RADDOG screens are shown in the following pages, in their recommended order of use. Subsidiary screens (not shown) may open during data entry within several of the main subject areas.

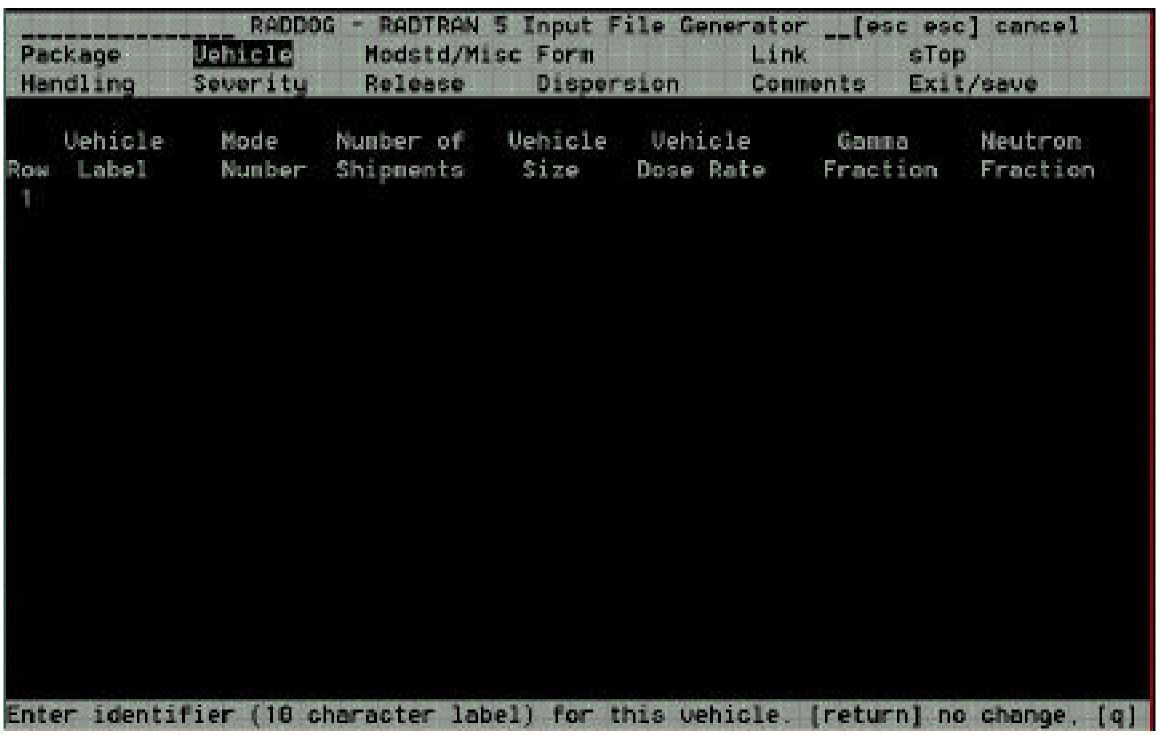
1. RADDOG Opening Screen



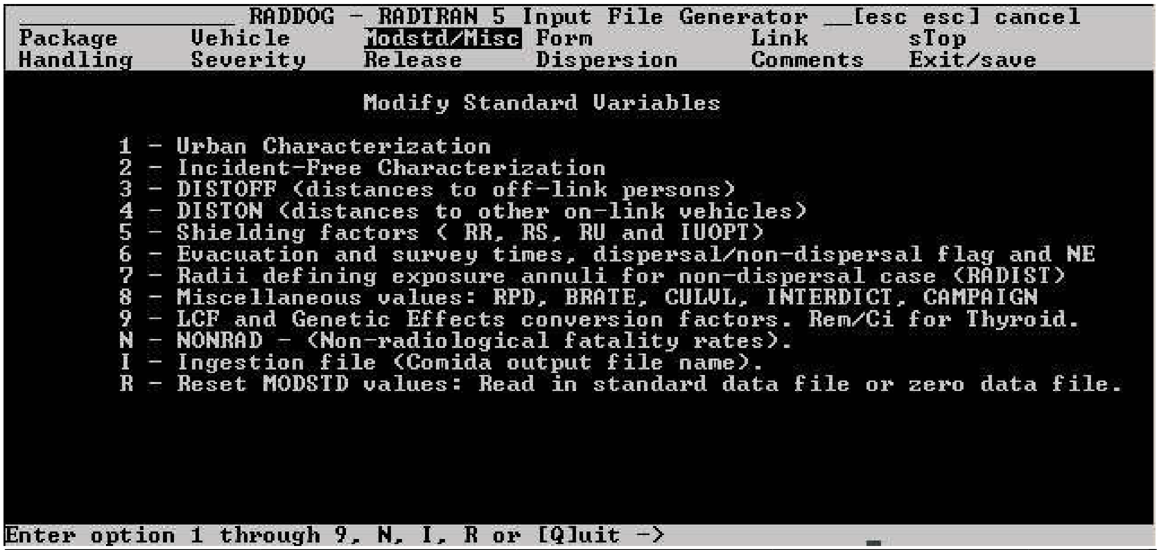
2. Main Screen as it looks before a subject area has been selected. Select by entering the appropriate capital letter after the > cursor and following instructions at bottom of screen.



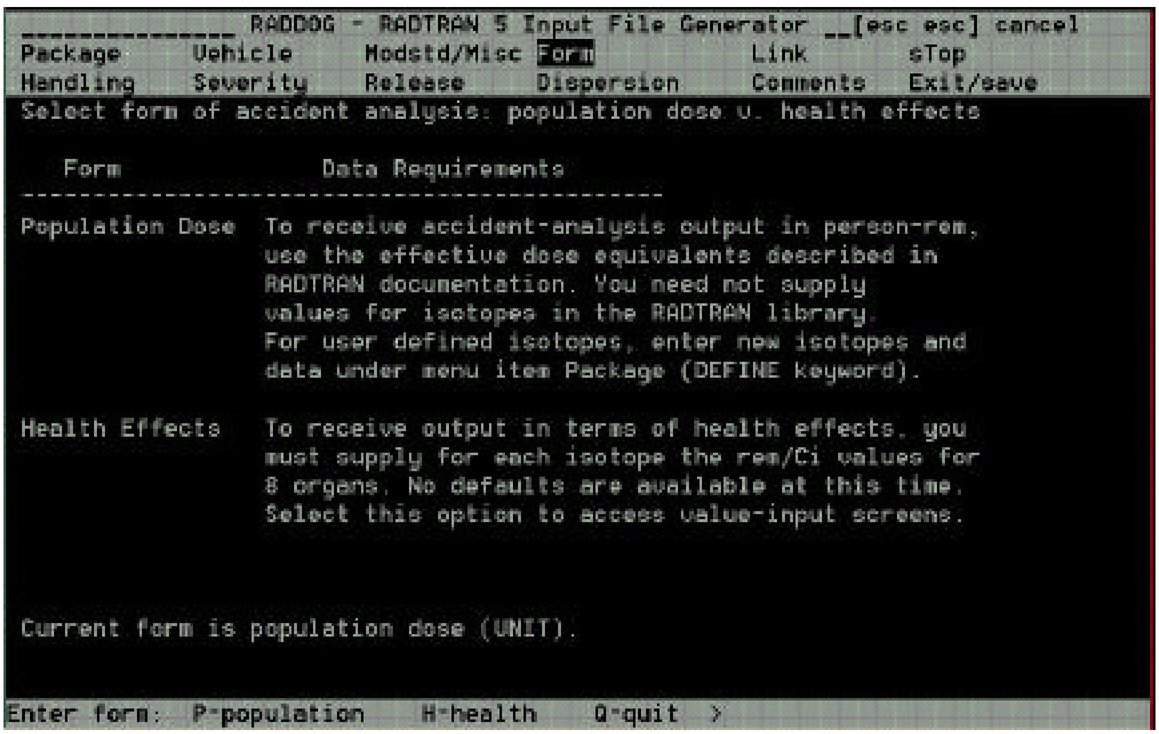
3. PACKAGE screen is first in recommended order. Enter data for each package type in analysis.



4. VEHICLE Screen. Enter data on a separate row for each vehicle in analysis.

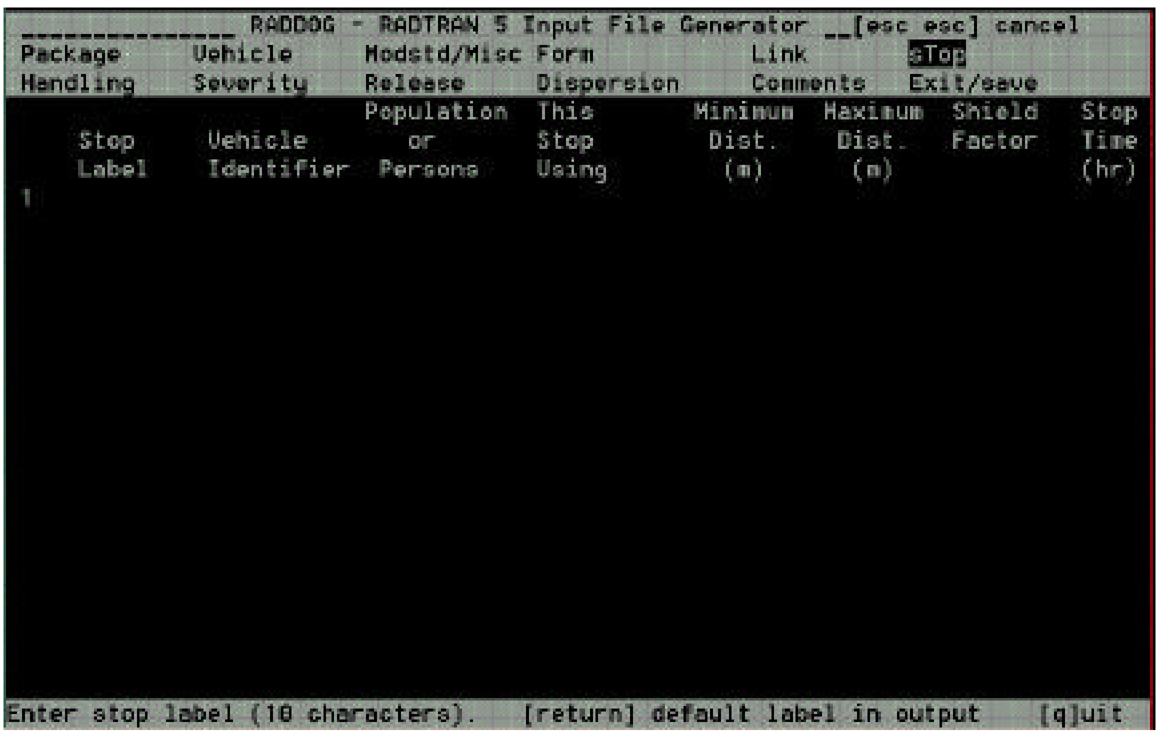


5. MODSTD Screen. Several subsidiary screens will open to allow entry of data under each topic for which user does not accept MODSTD values.

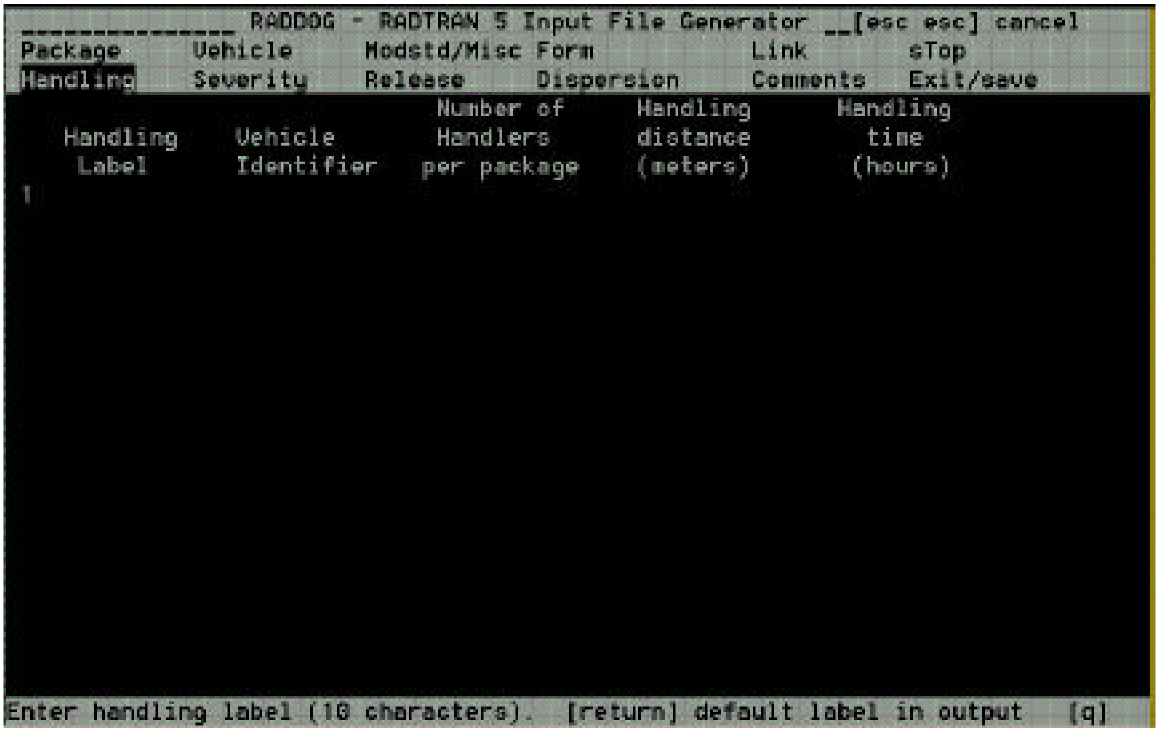


6. FORM Screen. Allows output format selection and tells user which option is currently selected.

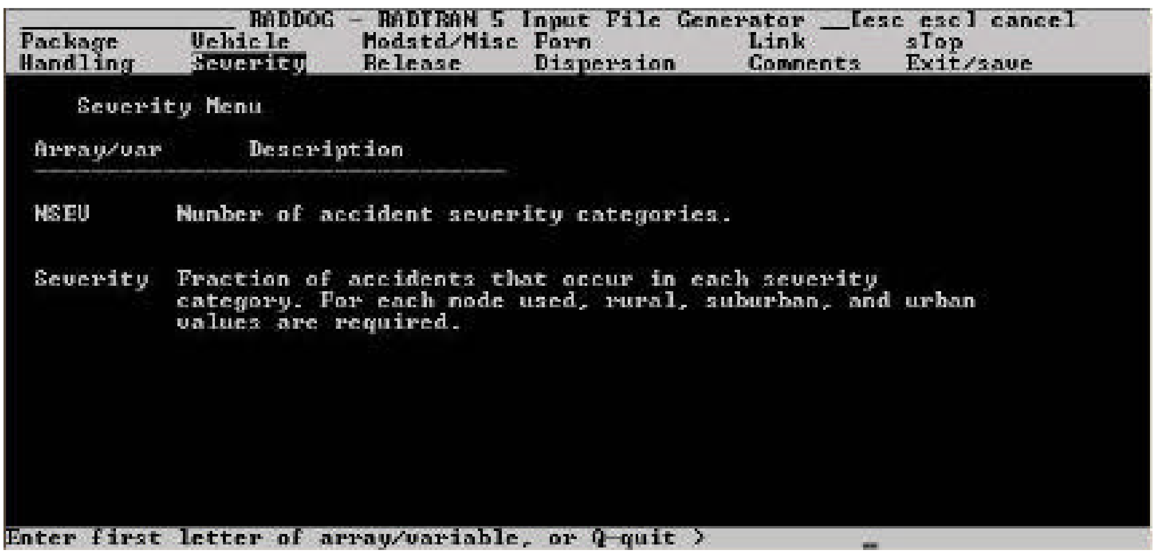
7. LINK Screen. Enter data as indicated for each link (route-segment) in analysis.



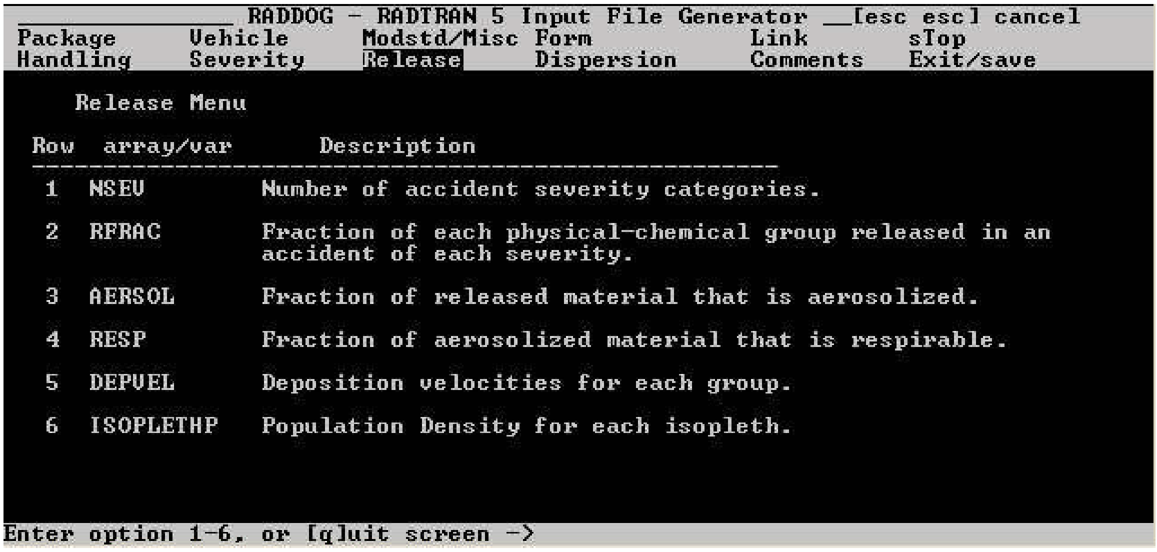
8. STOP Screen. Enter data for individual stops or aggregates.



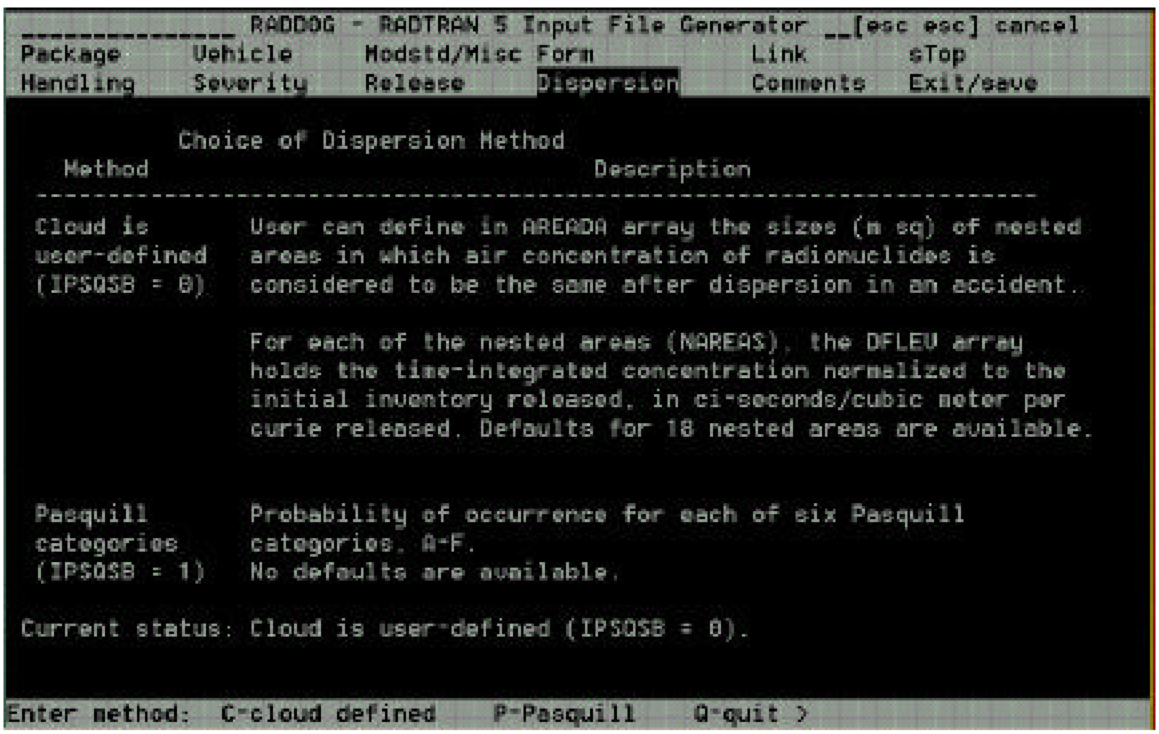
9. HANDLING Screen. Enter data for individual handlings or aggregates.



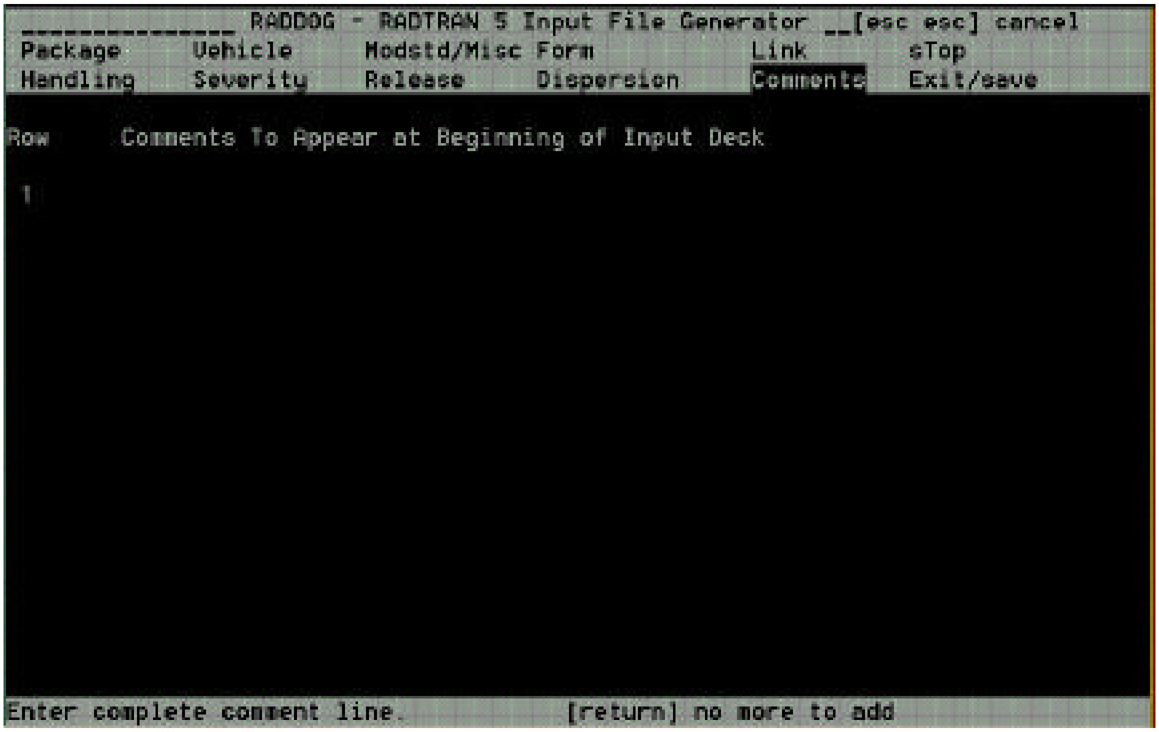
10. SEVERITY Screen. Enter data as indicated.



11. RELEASE Screen. Subsidiary screens will open to allow arrays to be entered.



12. DISPERSION Screen. User selects options; screen also shows current selection.



13. COMMENTS Screen. User is strongly recommended to take advantage of this capability.

11 APPENDIX E Radionuclide Data Base

Table E-1. 1-Yr Inhalation Dose Factors (REM/CI) for Lung & Marrow

NUCLIDE	LUNG	MARROW
H3WTR[a]	6.00E+01	6.00E+01
H3GAS[b]	1.20E+02	1.20E+02
C14ORG[c]	2.10E+03	2.10E+03
C14GAS[d]	2.40E+01	2.40E+01
P32	1.60E+05	1.10E+04
S35	0.00E+00	0.00E+00
CA45	0.00E+00	0.00E+00
CR51	0.00E+00	00.0E+00
MN54	4.10E+04	5.30E+03
FE55	5.80E+03	1.80E+02
FE59	8.6E+04	5.40E+03
CO58	1.00E+05	5.30E+03
CO60	7.90E+05	3.80E+04
ZN65	9.70E+04	1.10E+04
GA67	0.00E+00	0.00E+00
KR85	0.00E+00	0.00E+00
SR89	5.30E+05	2.90E+02
SR90	4.50E+06	3.80E+03
Y91	6.20E+05	8.70E+02
ZR95	2.50E+05	7.40E+03
NB94	0.00E+00	0.00E+00
NB95	5.30E+04	2.40E+03
MO99	2.70E+04	1.80E+02
TC99	1.00E+05	1.40E+02
RU103	9.90E+04	1.70E+03
RU106	4.30E+06	4.50E+03
SB125	4.40E+04	5.50E+02
TE125M	0.00E+00	0.00E+00
TE127M	2.10E+05	1.60E+04
TE127	2.70E+03	9.90E+00
TE129M	2.60E+05	9.60E+03
TE129	9.90E+02	1.80E+00
I125	6.80E+02	1.60E+02
I129	1.70E+03	4.30E+02
I131	4.00E+03	2.30E+02
XE133	0.00E+00	0.00E+00
CS134	4.10E+04	3.90E+04
CS137	3.10E+04	2.60E+04
CE141	1.10E+05	4.30E+02
CE144	3.60E+06	4.20E+03

Table E-1. 1-Yr Inhalation Dose Factors (REM/CI)

[a] Tritiated Water
[b] Tritium Gas
[c] Organic Carbon-14
[d] Carbon-14 in gaseous form (e.g., carbon dioxide)

for Lung & Marrow, *continued*

NUCLIDE	LUNG	MARROW
PM147	2.20E+05	5.30E+02
SM151	2.10E+04	2.90E+03
EU152	0.00E+00	0.00E+00
EU154	0.00E+00	0.00E+00
EU155	0.00E+00	0.00E+00
U233	4.00E+08	6.10E+03
U235	3.60E+08	1.00E+04
U238	3.50E+08	6.30E+03
NP237	1.00E+08	1.50E+07
PU236	4.30E+08	1.00E+06
PU238	4.50E+08	1.10E+06
PU239	4.20E+08	1.10E+06
PU240	4.20E+08	1.10E+06
PU241	3.60E+05	1.30E+03
PU242	4.00E+08	1.00E+06
AM241	1.20E+08	1.70E+07
AM243	1.10E+08	1.60E+07
CM242	9.90E+07	8.80E+06
CM244	1.20E+08	1.70E+07
CF252	8.60E+08	2.30E+06

Table E-2. Half-Life (days), Gamma Photon Energy (MeV), Cloudshine Dose Factor, Groundshine Dose Factor, and Nuclide Name-Format For Ingestion Dose Calculation

NUCLIDE	HALF-LIFE (DAYS)	PHOTON ENERGY (Mev)	CLOUDSHINE DOSE FACTOR	GROUNDSHINE DOSE FACTOR	INGESTION NAME FORMAT
H3WTR	4.51E+03	0.00E+00	1.22E-06	0.00E+00	NONE
HSGAS	4.51E+03	0.00E+00	1.22E-06	0.00E+00	NONE
C14ORG	2.09E+06	0.00E+00	8.29E-07	5.15E-09	NONE
C14GAS	2.09E+06	0.00E+00	8.29E-07	5.15E-09	NONE
P32	1.43E+01	0.00E+00	3.66E-04	9.30E-07	NONE
S35	8.74E+01	0.00E+00	8.99E-07	5.37E-09	S-35
CA45	1.63E+02	4.35E-08	3.19E-06	1.47E-08	Ca-45
CR51	2.77E+01	3.26E-02	5.59E-03	9.85E-06	Cr-51
MN54	3.13E+02	8.35E-01	1.51E-01	2.6E-04	Mn-54
FE55	9.86E+02	1.69E-03	0.00E+00	0.00E+00	Fe-55
FE59	4.45E+01	1.19E+00	2.21E-01	3.58E-04	Fe-59
CO58	7.08E+01	9.75E-01	1.76E-01	3.04E-04	Co-58
CO60	1.93E+03	2.50E+00	4.66E-01	7.51E-04	Co-60
ZN65	2.44E+02	5.84E-01	1.07E-01	1.77E-04	Zn-65
GA67	3.26E+00	1.58E-01	2.66E-02	4.76E-05	Ga-67
KR85	3.92E+03	2.21E-03	4.40E-04	8.44E-07	NONE
SR89	5.05E+01	8.45E-05	2.86E-04	7.26E-07	Sr-89
SR90	1.06E+04	0.00E+00	2.79E-05	9.08E-08	Sr-90
Y91	5.85E+01	3.61E-03	9.62E-04	1.83E-06	Y-91
ZR95	6.40E+01	7.39E-01	1.33E-01	2.31E-04	Zr-95
NB94	7.42E+06	1.57E+00	2.85E-01	4.89E-04	Nb-94
NB95	3.52E+01	7.66E-01	1.38E-01	2.39E-04	Nb-95
MO99	2.75E+00	2.76E-01	2.69E-02	8.09E-05	Mo-99
TC99	7.78E+07	0.00E+00	5.99E-06	2.49E-08	Tc-99
RU103	3.93E+01	4.70E-01	8.33E-02	1.48E-04	Ru-103
RU106	3.68E02	2.01E-01	0.00E+00	6.78E-05	Ru-106
SB125	1.01E+03	4.30E-01	7.47E-02	1.36E-04	Sb-125
TE125M	5.80E+01	3.55E-02	1.68E-03	1.15E-05	Te-125m
TE127M	1.09E+02	1.12E-02	5.44E-04	3.61E-06	Te-127m
TE127	3.90E-01	4.86E-03	8.95E-04	1.66E-06	NONE
TE129M	3.36E+01	9.66E-02	5.79E-03	1.21E-05	Te-129m
TE129	4.83E-02	5.91E-02	1.02E-02	1.92E-05	NONE
I125	6.01E+01	4.20E-02	1.93E-03	1.37E-05	I-125
I129	5.73E+09	2.46E-02	1.41E-03	8.25E-06	I-129
I131	8.04E+00	3.80E-01	6.73E-02	1.20E-04	I-131
XE133	5.25E+00	4.60E-02	5.77E-03	1.47E-05	NONE
CS134	7.53E+02	1.55E+00	2.80E-01	4.86E-04	Cs-134
CS137	1.10E+04	5.96E-01	2.86E-05	1.77E-04	Cs-137
CE141	3.25E+01	7.61E-02	1.27E-02	2.36E-05	Ce-141
CE144	2.84E+02	5.25E-02	3.16E-03	1.84E-05	Ce-144

Table E-2. Half-Life (days), Gamma Photon Energy (Mev), Cloudshine Dose Factor, Groundshine Dose Factor, and Nuclide Name-Format For Ingestion Dose Calculation

NUCLIDE	HALF-LIFE (DAYS)	PHOTON ENERGY (Mev)	CLOUDSHINE DOSE FACTOR	GROUNDSHINE DOSE FACTOR	INGESTION NAME FORMAT
PM147	9.58E+02	4.37E-06	2.56E-06	1.09E-08	Pm-147
SM151	3.29E+04	1.34E-05	1.34E-07	1.61E-09	Sm-151
EU152	4.87E+03	1.14E+00	2.09E-01	3.52E-04	Eu-152
EU154	3.21E+03	1.22E+00	2.27E-01	3.80E-04	Eu-154
EU155	1.81E+03	6.05E-02	9.21E-03	1.89E-05	Eu-155
U233	5.79E+07	1.31E-03	6.03E-05	2.29E-07	U-233
U235	2.57E+11	1.54E-01	2.66E-02	4.73E-05	U-235
U238	1.63E+12	1.36E-03	1.26E-05	1.76E-07	U-238
NP237	7.82E+08	3.43E-02	3.81E-03	9.17E-06	Np-237
PU236	1.04E+03	2.09E-03	2.35E-05	3.14E-07	Pu-236
PU239	8.79E+06	7.96E-04	1.57E-05	1.17E-07	Pu-239
PU240	2.39E+06	1.73E-03	1.76E-05	2.57E-07	Pu-240
PU241	5.26E+03	2.54E-06	2.68E-07	6.17E-10	Pu-241
PU242	1.37E+08	1.44E-03	1.48E-05	2.13E-07	Pu-242
AM241	1.58E+05	3.24E-02	3.03E-03	8.79E-06	Am-241
AM243	2.70E+06	5.59E-02	8.07E-03	1.71E-05	Am-243
CM242	1.63E+02	1.83E-03	2.11E-05	3.06E-07	Cm-242
CM244	6.62E+03	1.70E-03	1.82E-05	2.81E-07	Cm-244
CF252	9.64E+02	1.20E-03	1.87E-05	2.31E-07	NONE

Table E-3. 50-Yr Effective Dose (rem/Ci) for Inhalation Pathway and Conversion Factor for Gonad Dose (used to estimate genetic effects)

NUCLIDE	50-yr EFFECTIVE DOSE (rem/Ci)	GONAD DOSE FACTOR (rem/Ci)
H3WTR	6.30E+01	0.00E+00
H3GAS	4.40E+-03	0.00E+00
C14ORG	2.10E+03	3.80E+03
C14GAS	2.40E+01	0.00E+00
P32	2.20E+04	0.00E+00
S35	4.10E+03	0.00E+00
CA45	9.50E+03	0.00E+00
CR51	4.50E+02	0.00E+00
MN54	1.00E+04	2.70E+03
FE55	1.60E+03	2.20E+03
FE59	1.40E+04	1.30E+04
CO58	1.30E+04	0.00E+00
CO60	2.80E+05	0.00E+00
ZN65	2.80E+04	6.50E+03
GA67	5.90E+02	1.60E+02
KR85	0.00E+00	0.00E+00
SR89	6.70E+04	0.00E+00
SR90	2.40E+06	0.00E+00
Y91	8.00E+04	0.00E+00
ZR95	3.20E+04	7.90E+03
NB94	6.00E+05	0.00E+00
NB95	7.30E+03	1.30E+03
MO99	4.50E+03	0.00E+00
TC99	1.40E+04	0.00E+00
RU103	1.30E+04	0.00E+00
RU106	8.00E+05	0.00E+00
SB125	1.70E+04	0.00E+00
TE125M	1.00E+04	0.00E+00
TE127M	3.00E+04	0.00E+00
TE127	3.90E+02	0.00E+00
TE129M	3.40E+04	0.00E+00
TE129	1.10E+02	0.00E+00
I125	2.30E+04	0.00E+00
I129	1.70E+05	0.00E+00
I131	3.10E+04	0.00E+00
XE133	0.00E+00	0.00E+00
CS134	4.60E+04	4.60E+04
CS137	3.20E+04	3.20E+04
CE141	1.40E+04	0.00E+00
CE144	6.30E+05	0.00E+00

Table E-3. 50-Yr Effective Dose (rem/Ci) for Inhalation Pathway and Conversion Factor for Gonad Dose (used to estimate genetic effects), ***continued***

NUCLIDE	50-yr EFFECTIVE DOSE (rem/Ci)	GONAD DOSE FACTOR (rem/Ci)
PM147	6.00E+05	0.00E+00
SM151	3.30E+04	0.00E+00
EU152	2.60E+05	5.50E+04
EU154	3.10E+05	5.00E+04
EU155	4.80E+04	0.00E+00
U233	2.40E+08	0.00E+00
U235	2.20E+08	0.00E+00
U238	2.20E+08	0.00E+00
NP237	5.60E+08	1.30E+08
PU236	2.40E+08	3.90E+07
PU238	5.30E+08	1.10E+08
PU239	5.70E+08	1.40E+08
PU240	5.70E+08	1.40E+08
PU241	9.90E+06	2.90E+06
PU242	5.30e+08	1.30E+08
AM241	5.90E+08	1.40E+08
AM243	5.90E+08	1.4E+08
CM242	2.30E+07	0.00E+00
CM244	3.10E+08	6.80E+07
CF252	2.40E+08	0.00E+00

Distribution

1	1396	Steven Hamp, DOE/AL
14		Michael Keane, DOE/EM, Rm 1058,Cloverleaf Leaf Bldg, 19901 Germantown Rd. Germantown, Md 20874-1290
1	0718	Charles Massey, 6141
10	0718	Frances L. Kanipe, 6141
1	0718	G. Scott Mills, 6141
150	0718	K. Sieglinde Neuhauser, 6141
1	0718	Jeremy L. Sprung, 6141
10	0718	Ruth F. Weiner, 6141
1	9018	Central Technical Files, 8940-2
2	0899	Technical Library, 9616
1	0612	Review and Approval Desk, 9612 (for DOE/OSTI)
1		John Cook, Nuclear Regulatory Commission, Nuclear Materials Safety and Safeguards. MS 0-6-P-18, Washington, DC 20555
1		Tom McNamara, US Department of Transportation Rm 8108, DHM-60, 400 Seventh St., SW, Washington, DC 20590
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